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ILLUMINATED CHANCEL OF ST. JOHN'S ROMAN CATHOLIC CATHEDRAL, SALFORD

A Modern Rolling Mill Drive

AN INSTALLATION AT THE REDBOURN WORKS OF RICHARD THOMAS & BALDWINS, LTD.

By J. P. HUGGARD, B.Sc., M.I.E.E., and S. A. G. EMMS, B.Sc.
Witton Engineering Works.

INTRODUCTION.

IN modern rolling mills speed and accuracy of control combined with high efficiency and absolute reliability are essential features of both main and auxiliary drives. For such arduous service the electric drive is superior to all other forms of motive power, and this article describes one of the most recent examples of such equipment now in operation at the Redbourn Works of Richard Thomas & Baldwins, Ltd., Scunthorpe. The General Electric Co. Ltd. has supplied the whole of the electrical equipment for both main and auxiliary drives of the 42½ in. cogging mill, the G.E.C. cascade exciter control system being employed to ensure rapid and precise control of the mill.

The rolling mill at the Redbourn Works comprises a battery of gas-fired soaking pits, the 42½ in. cogging mill, a bloom shear and one 36 in. stand finishing mill; the average weekly output of the mill in billets and slabs is of the order of 6,000 to 6,500 tons finished weight.

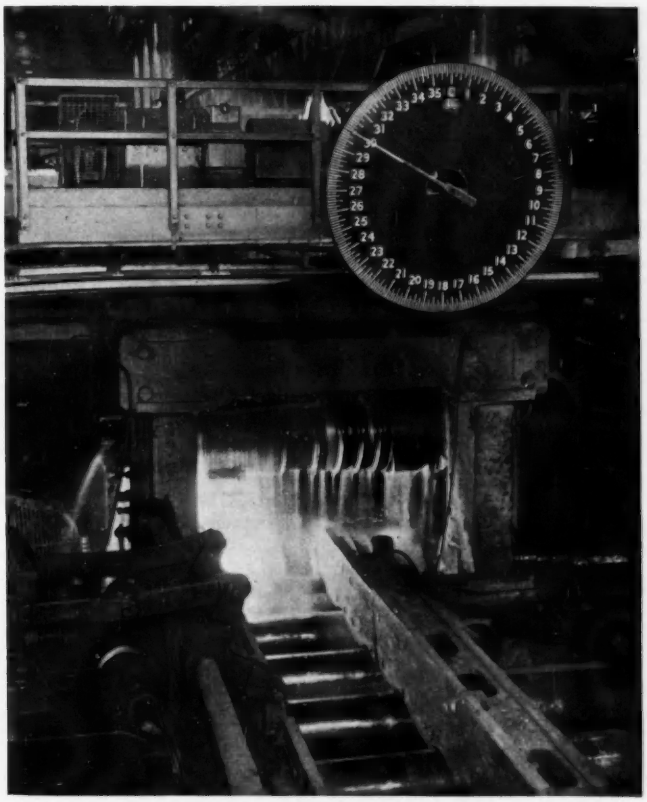

Fig. 1.—The 42½in. cogging mill at the Redbourn Works, showing an ingot entering the rolls.

There are four long type regenerative soaking pits fired with a mixture of blast furnace and coke oven gas, and a one-way fired pit burning coke oven gas. Each of these pits is capable of holding twenty of the standard 3-ton ingots or sixteen of the 5-ton slab ingots.

The soaking pit installation is completed by six Stein & Atkinson recuperative cubicles, mixed-gas fired and each capable of holding six 3-ton ingots or three 5-ton ingots.

The cogging stand has rolls with 42½ in. centres and 9 ft. barrel, and prior to the electrification these rolls were driven by a Galloway three-cylinder reversing steam engine. The products of the cogging mill are slabs varying from 9 ins. to 34 ins. in width and 1¾ ins. to 6 ins. in thickness, and blooms of 5 ins. square and upwards.

These are cogged from the standard 3-ton ingots of 20 in. square section or from the 5-ton slab ingots of 37½ in. by 19 in. cross section. The 3-ton ingot is reduced to a 5½ in. square bloom for the finishing mill in 19 passes, after which it passes to the down-cutting Davy shears, and is then passed to the single stand finishing mill which has rolls of 36 in. centres and 7 ft. barrel. Products of this mill are

Fig. 2.—The control pulpit of the cogging mill.

billets 2 ins. to 5½ ins. square and slabs from 4 ins. to 8 ins. wide by 2 ins. thick. Large slabs from the cogging mill by-pass this mill and are placed directly on to cooling beds.

The products of the finishing mill pass through an electrically-driven shear where they are cut to the required length before being pushed on to one of four cooling beds.

ELECTRICAL EQUIPMENT.

The cogging mill (fig. 1) is driven by a 5,000 h.p., r.m.s., D.C. motor housed in a motor room adjacent to the mill. The motor room also contains the Ward-Leonard Ilgner set which supplies power to the mill motor, the main switchboard and control desk, and the liquid starter and slip regulator for the driving motor of the Ward-Leonard set.

To prevent the ingress of dust from the mill, an air pressure of ¼ in. water gauge is maintained inside the motor room by means of two electrically-driven fans mounted in the roof. These fans, which also supply cooling air to the machines in the motor room, are driven by 90 h.p. squirrel cage induction motors running at 730 r.p.m. The basement of the motor room houses the main and cascade exciter sets for the mill drive, an auxiliary motor generator set and a cascade exciter set for the screwdowns and breast rolls and three reversible high-speed circuit breakers which protect the main generators.

For the screwdown and breast roll auxiliary drives standard steelworks motors are used and all drives are controlled from a desk (fig. 2) in a pulpit overlooking the mill.

The armature and magnet frame of the main mill motor are illustrated in figs. 3 and 4 and the complete motor in fig. 5. It is a compensated, shunt wound, reversing machine operating over a speed range of 0-50 r.p.m. by Ward-Leonard control and from 50-100 r.p.m. by shunt control and is rated at 5,000 h.p. r.m.s. at ± 700 volts, with a working peak of 12,500 h.p. at 50 r.p.m. and a maximum cutout peak of 15,000 h.p. at the same speed. It is equipped with two pedestal journal bearings which are flow-lubricated from motor-driven oil pumps and the oil circuit incorporates a flow indicator with alarm contacts.

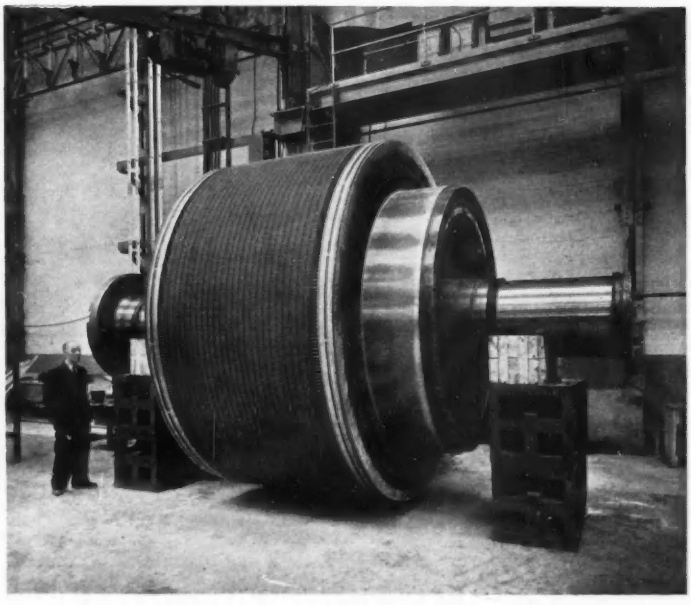

Fig. 3.—The armature of the 5,000 h.p. cogging mill motor.

Fig. 4.—The magnet frame of the cogging mill motor.

The D.C. supply for the main mill motor is provided by an Ilgner motor generator set (fig. 6) consisting of three D.C. generators directly coupled to a 3,000 h.p. slipring induction motor. The flywheel is 9 ft. 6 in. in diameter and 32¾ tons in weight and is designed to give a total stored energy of 150,000 h.p. seconds. The induction motor, which operates from an 11 kV supply and drives the set at approximately 735 r.p.m., has a synchronous speed of 750 r.p.m. and a maximum operating peak of 6,000 h.p. for 15 seconds. Each of the three generators has an output of 1,333 kW r.m.s. at 700 volts and a maximum operating peak of 3,332 kW for 15 seconds. The three machines are normally connected in parallel but changeover links are provided to enable the mill to be run at reduced output with any selected pair of generators. The machines are fitted with forced-lubricated bearings, which, with the exception of the two outer bearings, are water-cooled. The flywheel runs in swivelled pedestal bearings, 13 ins. in diameter and 27 ins. long, which are also forced-lubricated and all bearings are fitted with pressure gauges and dial type thermometers with alarm contacts. The lubrication equipment for normal operation comprises two geared oil pumps which are belt-driven from the flywheel shaft, but for starting up and standby purposes

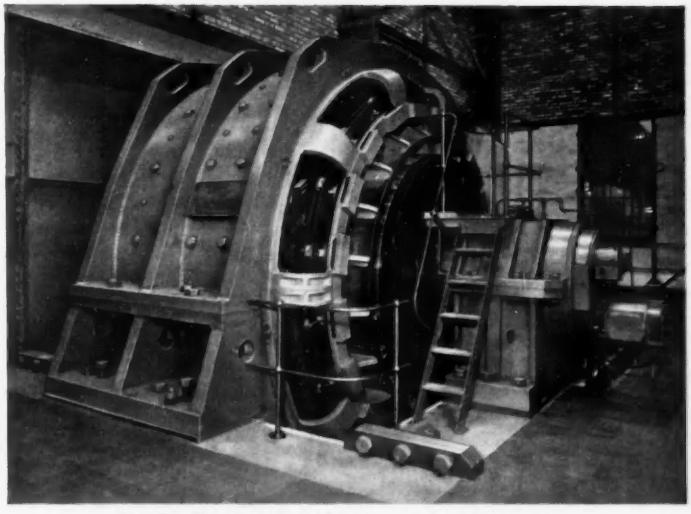

Fig. 5.—The cogging mill motor in the motor room.

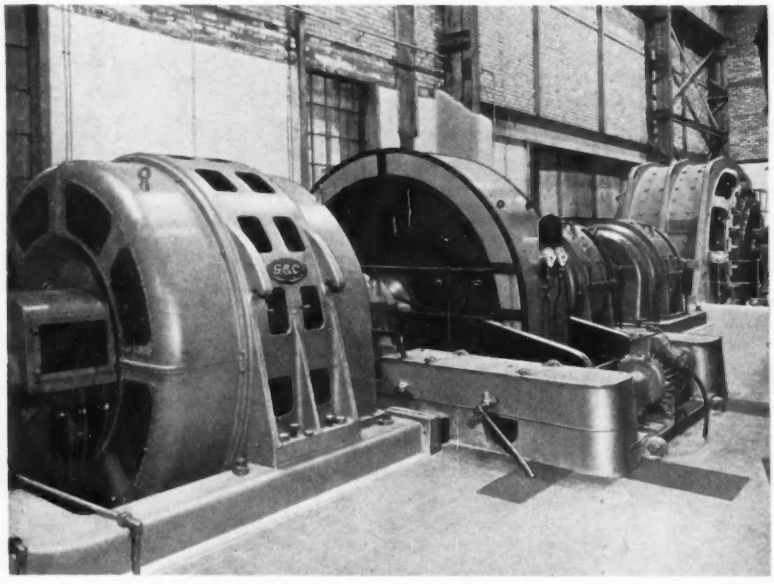

Fig. 6.—3,000 h.p. Ward-Leonard Ilgner set in the motor room.

two electrically-driven pumps are provided. The four pumps which supply cooling water to the bearings of the Ilgner set are driven by 460 volt squirrel cage induction motors rated at 5 h.p. at 1,440 r.p.m.

The basement of the motor room (fig. 7) houses four motor generator sets, each of which is driven by a protected type squirrel cage induction motor. Two of the sets provide the excitation for the main drive and the others are associated with the D.C. supplies for the auxiliary drives. The functions and ratings of the various machines are given in the table on page 199.

The screwdown motors are of the standard steelworks type and are rated at 100/200 h.p., 230/460 volts, 475/950 r.p.m. They are mounted on a platform above the cogging mill and are forced-ventilated from the main ventilating fans in the motor room. The breast roll motors are also of the steelworks type and are rated at 25 h.p., 230 volts, 1,300 r.p.m.

Fig. 7.—Motor generator and cascade exciter sets in the basement of the motor room.

The main switchboard for the control of the D.C. and auxiliary A.C. supplies is of the open flatback type and is designed for remote operation from control desks in the motor room and the mill pulpit. The motor room desk, which controls the mill motor generator set, the screwdown and cascade exciter sets and all the auxiliary A.C. drives, is shown together with a portion of the main switchboard in fig. 9. Each starter is controlled by means of start and stop push buttons with red and green indicator lamps, and sequence interlocking is provided. The desk is fitted with an annunciator panel which indicates any failure in the auxiliary A.C. circuits and audible warning of the fault is also given by means of a Klaxon horn mounted on the main switchboard. The mill will continue to run for a period of three minutes from the occurrence of such a fault, to enable a newly started ingot to be finished, and at the end of this time the whole mill is automatically shut down.

The main drive, screwdowns and breast rolls are controlled from the mill pulpit desk by means of cam type reversing controllers. Similar controls are provided for the ingoing and outgoing racks and the desk is fitted with a speed indicator for the main drive and a position indicator for the screwdowns. A " stop " push button placed in the centre of the desk in a position convenient to both operators enables the complete mill to be shut down in the event of an emergency.

The liquid starter and slip regulator for the 3,000 h.p. induction motor of the main motor generator set is shown in fig. 10. The moving and fixed electrodes are phosphor bronze grids operating in rubber-lined steel pots which are entirely immersed in the solution. In the full-in position the fixed and moving electrodes are prevented from making contact with each other, the amount of resistance left in circuit being such that the slip is limited to 10 per cent at the full load torque of the motor. The electrolyte is circulated by a 1½ h.p. pump and the liquid starter is operated by a D.C. motor fitted with limit switches and interlocking contacts.

CONTROL SYSTEM.

The cascade exciter control scheme which has been adopted for the main mill and screwdown drives is a method of energising the field of a large generator in such a manner that the excitation can be varied and, if necessary, reversed, in the minimum of time and by the expenditure of a very small amount of electrical energy in the initiating circuit. The cascade exciter scheme is used in conjunction with Ward-Leonard control and is applied to the fields of the generators which supply the main driving motors.

To change or reverse a large field quickly, an exciter giving a maximum voltage of up to six times the normal field voltage is required and such an exciter requires appreciable power in its own field circuit. By using a pilot exciter to

DESCRIPTION	GENERATORS				DRIVING MOTOR
	For Main Drive Excitation*				
Exciter sets	Generator field exciter *GFE*. 9·6 kW	Mill motor exciter *MFE*. 22/200 kW	Constant voltage exciter *CVE*. 40 kW	—	140 h.p. 2,200 V. 970 r.p.m.
	Main exciter *ME*1. 1 kW	Pilot exciter *PE*1. 1 kW	Main exciter *ME*2. 1 kW	Pilot exciter *PE*2. 1 kW	40 h.p. 460 V. 1,450 r.p.m.
	For Auxiliary Drives				
M.G. set.	Screwdown generator 1. 85/170 kW	Screwdown generator 2. 85/170 kW	Breast roll generator. 0/44 kW	—	575 h.p. 2,200 V. 970 r.p.m.
Screwdown cascade exciter set.	Screwdown generator exciter *SGE*1. 2·15 kW	Pilot exciter for *SGE*1. 2·15 kW	Screwdown generator exciter *SGE*2. 2·15 kW	Pilot exciter for *SGE*2. 2·15 kW	40 h.p. 460 V. 1,450 r.p.m.

* The machines are connected in cascade as follows :
Exciters *GFE*, *ME*1 and *PE*1 for the excitation of the Ilgner generator.
Exciters *ME*2 and *PE*2 for the mill motor exciter *MFE*.

provide the excitation of the main exciter, the power required to initiate a change in the main generator field is reduced, and if the pilot exciter is also designed to give a far higher voltage than is normally required, a rapid response is obtained. To ensure this rapid response both exciters must have completely laminated iron circuits, but apart from this feature and the provision of two additional field windings on the pilot exciter to prevent hunting, they are standard D.C. machines.

Hunting is prevented by connecting one of the additional windings on the pilot exciter across the output of the main exciter and the other in series with the armature of the main exciter. Under steady conditions the windings neutralise each other and there is no resultant effect on the field. When the current in the main generator field is changing the pilot fields are unbalanced by the inductance of the generator field and an extra magnetising force is applied to the exciter field which has the effect of preventing the system from hunting.

For the control of the main mill motor, which has an armature weighing 58 tons, three exciters connected in cascade are employed and with this system the change from full speed forward to full speed reverse can be accomplished in 5½ seconds, the corresponding time for base speed forward to base speed reverse being two seconds.

A simplified schematic diagram of the main control circuit is shown in fig. 8. The mill motor is connected in a closed loop circuit with the three generators, the fields of which are connected in parallel and are energised by a generator field exciter *GFE*. The connection between this exciter and each generator field is made by a "suicide" contactor *SC*, and when the machines are stopped this contactor also connects the field windings to the armatures of the generators to prevent circulating currents and "creeping".

Exciter *GFE* is excited from the main exciter *ME*1, which in turn is excited from pilot exciter *PE*1, which has four field windings, *B*1, *C*1, *A*1 and *D*1. *B*1 and *C*1 are arranged to receive current and voltage signals from the succeeding stages of the cascade system and their function is to stabilise the system. Control winding *A*1 receives a voltage which is the difference between a reference voltage selected by the master controller and a suitable fraction of the generator voltage. At steady speed the small difference between these is sufficient to produce the required generator excitation. Winding *D*1 is arranged to provide a current limiting feature and opposes or assists winding *A*1 when rapid changes in the reference voltage would otherwise cause overcurrents in the main loop circuits.

The mill motor is excited by a motor field exciter *MFE* which is excited by a main field exciter *ME*2, this in turn being excited by a pilot exciter *PE*2. Exciter *MFE* has two field windings *A* and *B*, of which *A* provides the maximum field current required for the main motor. Winding *B* is excited by *ME*2 and opposes *A* to provide the reduction in the main motor field required to give maximum speed and also the forcing necessary to ensure rapid response to a control signal.

Pilot exciter *PE*2 has four field windings, *C*2, *B*2, *A*2 and *D*2. Of these *C*2 and *B*2 are stabilising windings and *A*2 receives the difference between a reference voltage selected by the master controller and a voltage derived from a tachometer generator *TG*1. At steady speed the small difference between these voltages is sufficient to reduce the excitation of *MFE* and hence of the motor, to the value required by the position of the master controller. Winding *D*2 is arranged to provide a current limiting feature which is similar to that provided by winding *D*1 on exciter *PE*1 and is described in detail below.

The rectifier systems *R* and *R*1 in conjunction with the current limit selector *E* and windings *D*1 and *D*2 of the pilot exciters, limit the maximum current passing in the main loop circuit in the following manner. Below the basic speed of 50 r.p.m. the contacts *E* connect *D* in series with the main motor compole and compensation windings to the points *Y* and *Z* of the rectifier *R*1. The points *WX* of this rectifier are supplied with an adjustable voltage from potentiometer *P* which is energised by rectifier *R*.

So long as the voltage across *WX* exceeds the voltage drop across *L*, no current can pass through winding *D*1. If the main loop current increases until the voltage across *L* exceeds that across *WX*, a current will pass through *D*1 and this current will oppose any change in *A*1. Thus a rapid motion of the master controller from "zero" to "basic speed" will first raise the generator excitation until the current in the loop exceeds the limit set by the voltage applied to the points *WX*. Any further increase in the pilot voltage will be checked until the acceleration of the motor causes a fall in line current and this sequence continues until basic speed is reached. During retardation the main loop current controls the rate of fall of the voltage from *PE*1 in a similar manner. During acceleration above basic speed the current limit is transferred by relay *E* to exciter *PE*2, where it acts in a similar manner but in opposite sense, the generator meanwhile remaining at full voltage.

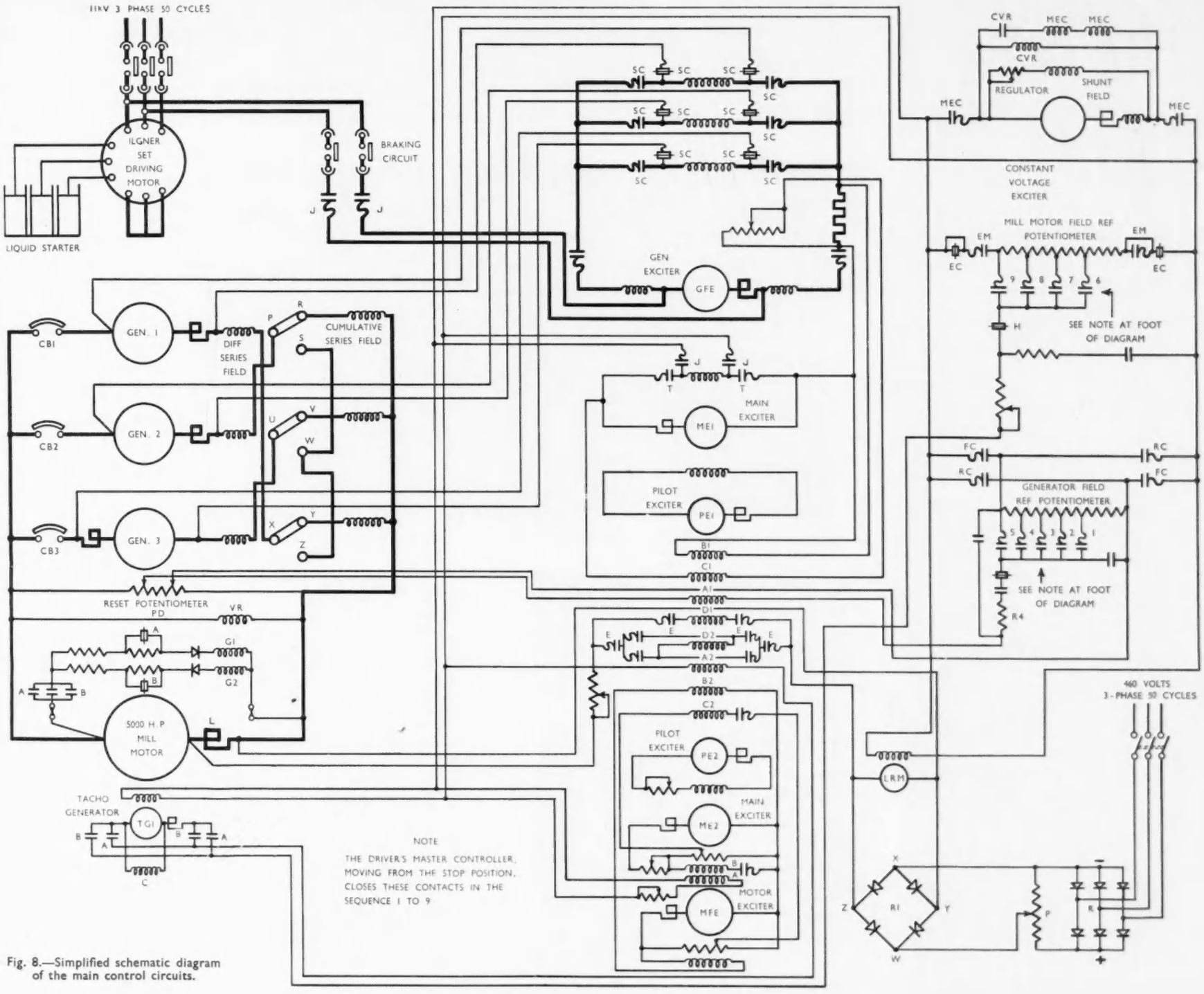

Fig. 8.—Simplified schematic diagram of the main control circuits.

OPERATION.

"STOP" TO "BASIC SPEED".

On moving the master controller from "stop" to "basic speed forward", contactor *FC* closes, energising the generator field reference potentiometer for forward running and full reference voltage is applied to *A*1. The voltage from pilot exciter *PE*1 rises rapidly, exciting in turn *ME*1, *MFE* and the generator fields. The generator voltage rises rapidly and a heavy current is built up in the main loop circuit, so that the voltage drop across *L* increases until it exceeds the reference voltage from *R*. A current proportional to this excess will circulate through *D*1, thus keeping the loop current to the limit set by *R*.

The mill motor accelerating under current control will quickly reach basic speed, and at this point the loop current will fall, the current in *D*1 will be zero and the mill will run steadily at basic speed. A similar sequence will take place if the master controller is moved to "basic speed reverse", except that contactor *RC* will close instead of *FC*, thus reversing the reference voltage.

"BASIC SPEED" TO "STOP".

When the master controller reaches the "stop" position contactor *FC* is opened and field *A*1 is directly connected to potentiometer *PD*. This causes a rapid reduction in the voltage of *PE*1, *ME*1, *MFE* and the generators, so that the mill motor regenerates and feeds a heavy current into the loop circuit. As soon as the consequent voltage drop across *L* exceeds the reference voltage from *R*, a current will pass through *D*1 in a direction opposite to that during acceleration. This current will, therefore, oppose the voltage from *PD*, keeping the generator voltage up and limiting the regenerated current to the preset figure. Finally the falling generator voltage releases relay *VR*, which in turn releases *SC* and makes the "suicide" connection through contacts *SC*1.

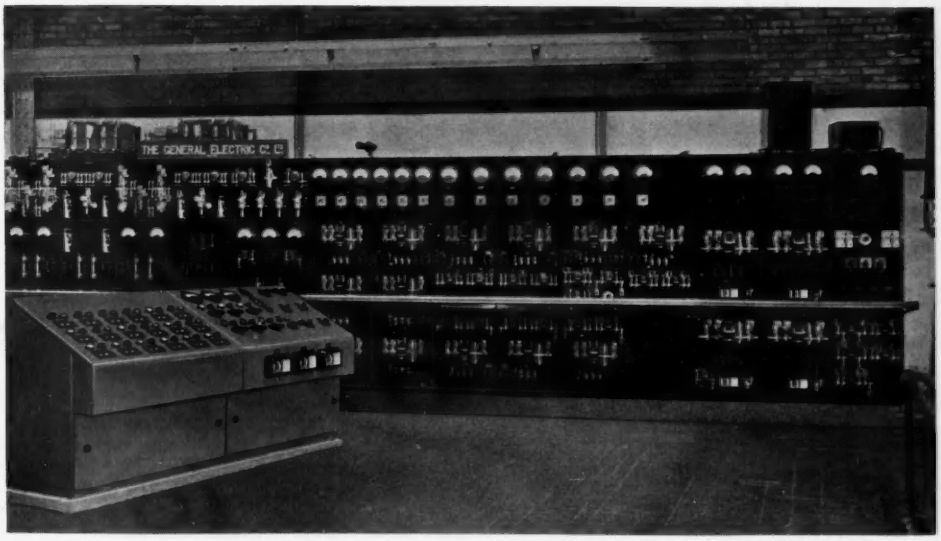

Fig. 9.—Control desk and contactor switchboard in the motor room.

"STOP" TO "FULL SPEED".

Acceleration up to basic speed takes place as previously described. Relay *G* then closes and in turn closes relay *A*, which selects the correct polarity of tacho-generator *TG*1 for forward running and then closes contactor *E*. This transfers the current limit from *PE*1 to *PE*2 and closes the circuit of exciter field *A*2, which now receives a voltage proportional to the difference between the voltage from the motor field potentiometer and the output of the tacho-generator.

Field *A*2 acting in opposition to *D*2 causes a weakening in motor excitation and a rapid rise in the current in the main loop circuit, which

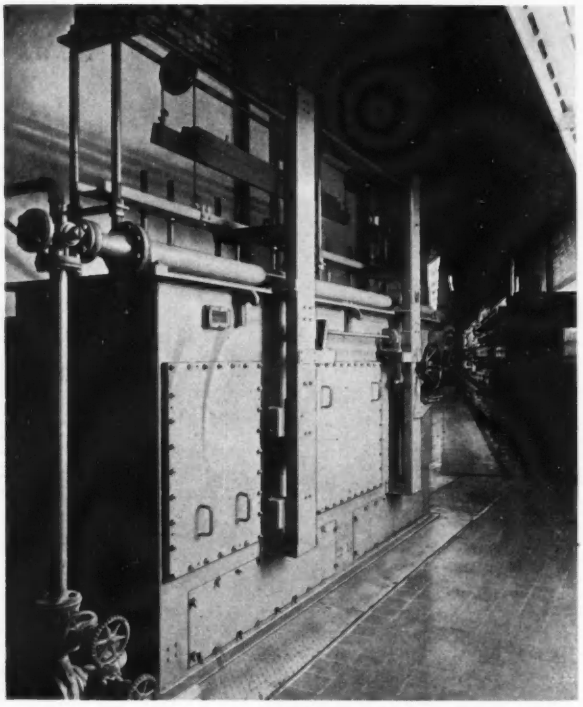

Fig. 10.—The liquid starter and slip regulator for the 3,000 h.p., 11 kV motor driving the ligner set.

brings into operation the current limit feature previously described.

"Full Speed Forward" to "Stop"

When the master controller is moved to "stop" both reference potentiometers are disconnected and contactor *FC* is held closed so that full reference voltage is maintained for generator control. The motor reference voltage is meanwhile reduced to zero and tacho-generator *TG*1 is short-circuited through pilot exciter field *A*2. This gives the maximum "lower speed" signal to the motor exciter system, so that the motor field is strengthened at a rate controlled by the current limit.

At basic speed relay *C* opens, in turn opening *A* and *E* and so reconnecting field *A*1 to its reference potentiometer, which is at zero. The maximum "lower voltage" signal is given to *A*1 and this generator field is then rapidly weakened under current limit control, which has been restored by the opening of *E*. Finally, at low voltage, contactor *SC* makes the suicide connection under the control of voltage relay *VR*.

"Full Speed Forward" to "Full Speed Reverse".

Contacts on the master controller disconnect exciter field *A*2 from the reference potentiometer and by short-circuiting the tacho-generator through *A*2, cause the maximum "lower speed" signal to be given to exciter *PE*2. The motor field is thus rapidly strengthened under current limit control. The generator field is unaffected until relay *C* opens at basic speed, in turn opening *A*. Contacts *RC* are then closed, thus reversing the reference potentiometer, and limiting resistance *R*4 is introduced into the reference circuit to avoid an unduly heavy signal to exciter field *A*1. This field receives the maximum "lower speed" signal and rapidly reduces the exciter voltage under current limit control. Acceleration in the reverse direction then takes place as previously described.

ACKNOWLEDGMENT.

Acknowledgment is due to Richard Thomas & Baldwins, Ltd., for permission to publish the foregoing information and illustrations.

Colour and Lighting

(Part 3)

QUANTITATIVE ASSESSMENT OF SUBJECTIVE COLOUR-RENDERING

By G. T. WINCH, M.I.E.E., F.Inst.P., F.I.E.S. and BRENDA M. YOUNG, B.Sc.
G.E.C. Research Laboratories

The work described in this article is an extension of that in "Colour and Lighting" (Part 2), Vol. XVIII, No. 2 of this Journal, page 88, April, 1951.

Improvements to the special form of binocular viewing apparatus are recorded and further results are given of subjective colour-rendering properties under artificial north light and sunlight, and under light from tungsten filament and fluorescent discharge lamps. The present results confirm earlier work and indicate quantitatively the extent to which in practical situations the subjective colour appearance of objects may change due to chromatic adaptation of the eye and simultaneous colour contrasts.

It is also shown that the coloured decorations and furnishings in a room may affect the overall colour-rendering to an extent comparable with that which can occur due to the use of light sources of different colours and spectral distributions. This emphasises the importance of designing a lighting installation, having in mind the particular decorations and furnishings.

(1) INTRODUCTION.

IN Part 1 of "Colour and Lighting"[1] reference was made to the earlier fundamental work of Helmholtz, Judd, Wright and Hunt on the subjective appreciation of colours under different conditions and the manner in which such colour judgments depart from those made under the C.I.E. Standard Observer conditions. Attention was drawn to Judd's formulæ which enable estimates to be made of the subjective colour-rendering under a limited number of viewing conditions.

In Part 2 of "Colour and Lighting"[2] reference was made to the binocular viewing technique which had been used by Wright, Hunt and Tadros for fundamental investigations on colour vision. A new apparatus, developed by the authors, was also described, which enabled binocular comparisons to be made in conditions simulating those experienced in practice, as for example when viewing coloured objects in a room. By this method the subjective colour appearance of test samples could be recorded objectively in the C.I.E. system by means of the photoelectric Physical Eye Colorimeter and Spectrophotometer. Preliminary results were given which had been obtained using this new binocular viewing apparatus. These provisional results indicated quantitatively, in terms of objectively measured chromaticity co-ordinates, the extent to which the colours of objects tended to appear constant under full radiator illuminants operated at different colour temperatures. It is interesting to note that similar conclusions have since been drawn by Helson, Judd and Warren in a recent paper,[3] using a different technique.

The present article gives further results obtained in the extended programme of work on subjective colour-rendering under daylight and light from tungsten filament and fluorescent electric discharge lamps. The object of this section of the work was to obtain data on the extent to which the subjective colour appearance of objects varies, depending on the conditioning of the observer due to the particular light source and viewing conditions.

(2) IMPROVED BINOCULAR VIEWING APPARATUS.

Several minor improvements have been made to the binocular viewing apparatus, described earlier, which have greatly facilitated its operation. Figs. 1 and 2 show in diagrammatic form the new arrangement in which the three colour pro-

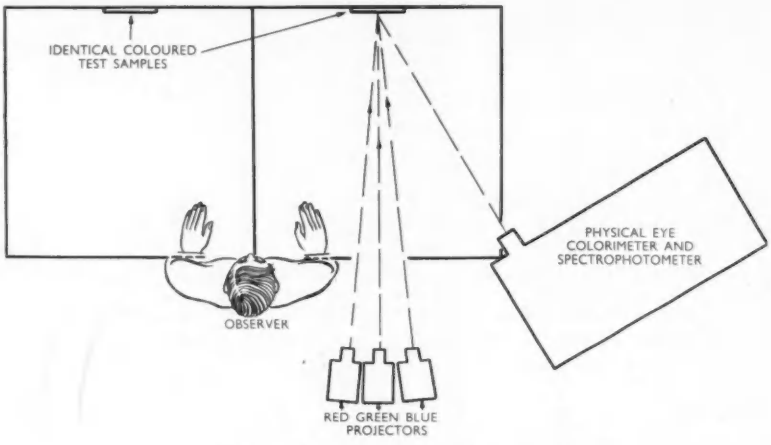

Fig. 1.—Binocular viewer : horizontal section.

jectors, originally used inside the viewing cabinet, are now placed outside the right-hand viewing compartment and project their light through an aperture in the door. The projectors are now more readily accessible so that the changing of coloured filters and adjustments to the projectors can more easily be made.

The instrument is now housed under a skylight facing north and either viewing compartment can be illuminated by natural daylight by removing the boxes containing the artificial light sources. In order to facilitate the adjustment of the illumination level in the cabinets, venetian shutters have been fitted immediately above the opal glass windows which form secondary sources illuminating the cabinets.

In the earlier preliminary investigations the simulation of Standard Illuminants *B* and *C* was achieved by illuminating the appropriate viewing cabinet by tungsten filament lamps operating at 2,850 degs. K. and arranging colour-temperature conversion filters in front of the observer's eye. The advantage of this technique was that small 2 in. square filters could be used. With this arrangement, however, it was not possible to view the effect of Standard Illuminants *B* or *C* in simultaneous comparison with a different illuminant in the adjacent cabinet. In order to overcome this limitation

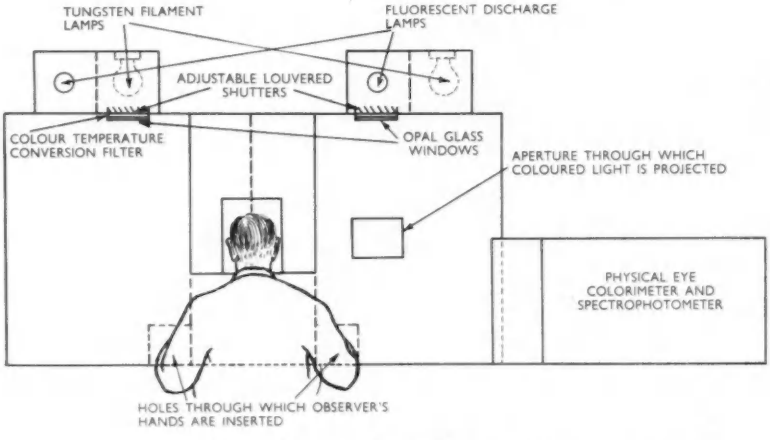
TUNGSTEN FILAMENT LAMPS
FLUORESCENT DISCHARGE LAMPS
ADJUSTABLE LOUVERED SHUTTERS
COLOUR TEMPERATURE CONVERSION FILTER
OPAL GLASS WINDOWS
APERTURE THROUGH WHICH COLOURED LIGHT IS PROJECTED
PHYSICAL EYE COLORIMETER AND SPECTROPHOTOMETER
HOLES THROUGH WHICH OBSERVER'S HANDS ARE INSERTED

Fig. 2.—Binocular viewer : front elevation.

large filters are now used, consisting of sections of Chance OB8 glass 6½ ins. × 1½ ins., of the appropriate thickness. These are mounted in frames so that the total filter area is sufficient to cover the whole of the diffusing windows forming the secondary light sources in the top of the cabinets. One of the frames contains filters which will convert the light from tungsten filament lamps operating at 2,850 degs. K. to Standard Illuminant *B*, while the other frame of filters converts to Standard Illuminant *C*. Either of these two frames can be inserted in a slide immediately above the diffusing windows in the top of the two viewing cabinets.

In the preliminary work previously published[1] the inside walls of the viewing cabinets were white. In order to study the effect of coloured wall decorations and furnishings on the subjective colour appearance of objects in a room, three sets of detachable panels have now been made which form a lining for the compartments of the binocular viewer. These three sets of panels have been painted with a matt finish in white, cream and pink, respectively, and other colours will be used later.

In all the tests described in the following sections of the paper, the same series of pairs of coloured test samples have been used, as in the earlier published work.

(3) SUBJECTIVE COLOUR-RENDERING UNDER DAYLIGHT AND TUNGSTEN LIGHT.

Supplementary to the preliminary work previously described,[2] an interesting series of measurements has been made in the binocular viewer, comparing the subjective colour-rendering properties of light from tungsten filament lamps with that of daylight in all its phases. The light sources used for this purpose have been tungsten filament lamps operating at 2,850 degs. K. (Standard Illuminant *A*), artificial sunlight (Standard Illuminant *B*, approximately 4,800 degs. K.), and artificial north sky light (Standard Illuminant *C*, approximately 6,500 degs. K.). The mean results of these subjective comparisons carried out by conditioned observers are plotted in C.I.E. chromaticity diagrams in figs. 3 and 4. To facilitate the interpretation of these data, the scale of colour differences in the chromaticity diagrams is indicated by the superposition of ellipses representing ± 10 minimum perceptible colour differences in the MacAdam system. Similar ellipses have also been included on figs. 5, 6, 8 and 9. In fig. 3 have been plotted the objective chromaticities of six of the eight coloured test samples under Standard Illuminant *A*. The chromaticities of the same series of test samples under Standard Illuminant

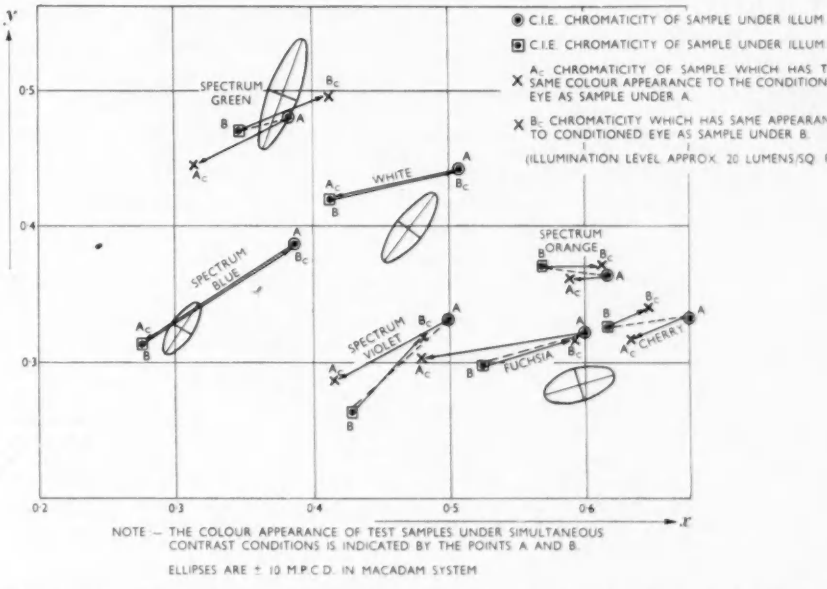
C.I.E. CHROMATICITY OF SAMPLE UNDER ILLUM. A.
C.I.E. CHROMATICITY OF SAMPLE UNDER ILLUM. B.
A_C CHROMATICITY OF SAMPLE WHICH HAS THE SAME COLOUR APPEARANCE TO THE CONDITIONED EYE AS SAMPLE UNDER A.
B_C CHROMATICITY WHICH HAS SAME APPEARANCE TO CONDITIONED EYE AS SAMPLE UNDER B.
(ILLUMINATION LEVEL APPROX. 20 LUMENS/SQ. FT.)
SPECTRUM GREEN
WHITE
SPECTRUM BLUE
SPECTRUM ORANGE
SPECTRUM VIOLET
FUCHSIA
CHERRY
0·5
0·4
0·3
0·2
0·3
0·4
0·5
0·6
y
x
NOTE — THE COLOUR APPEARANCE OF TEST SAMPLES UNDER SIMULTANEOUS CONTRAST CONDITIONS IS INDICATED BY THE POINTS A AND B.
ELLIPSES ARE ± 10 M.P.C.D. IN MACADAM SYSTEM

Fig. 3.—Chromaticity diagram, showing change of appearance of coloured samples by change of conditioning from tungsten light S_A to daylight S_B.

B have also been plotted. Where practicable, these pairs of points have been joined by a dotted line and the colour name of the test sample indicated. The plotted positions of the chromaticities of the samples indicate the large differences in colour under the two illuminants which would be experienced in the C.I.E. Standard Observer viewing conditions, namely in simultaneous comparison in a 2° field at high luminance. These colour differences were apparent if the observer stood back from the binocular viewer and looked into the two compartments simultaneously with both eyes. When, however, the eyes were adapted, respectively, to the illuminants and surrounding fields formed by the walls of the cabinets, these differences appeared to be reduced. The subjective colour appearance of the samples under these conditions, as measured objectively, is indicated by the points marked A_c and B_c. For example, for the colour sample "spectrum orange" the plotted point A_c represents the subjective colour appearance of the sample to the eye conditioned to Standard Illuminant *A* as compared with the subjective colour appearance to the eye conditioned to Standard Illuminant *B*. In this example it will be seen that there is a measure of compensation although there is still a small residual colour difference. The extent of this difference is indicated by the distance between the plotted points *A* and B_c or *B* and A_c. In the case of the "spectrum blue" colour sample, after conditioning to the respective illuminants, there was no noticeable colour difference; this is shown by the coincidence of the points *A* and B_c or *B* and A_c.

It will be noticed from fig. 3 that in this experiment there is almost complete compensation for the bluish colours, but only partial compensation for the orange to red colours.

A similar trend is noticeable when comparing the coloured test samples under Standard Illuminants *A* and *C* as indicated in fig. 4, although in this case the extent of the subjective compensation is not so great as when the eyes are conditioned to Standard Illuminants *A* and *B*, respectively.

It is important to note that the subjective colour appearance under these various conditions of observation is dependent, not only on the conditioning of the eye, but also on the simultaneous colour contrasts in the field of view. This applies to the binocular viewing experiments here described and also to common experience when observing coloured articles in a room. In general, the effects of conditioning are greater than those due to simultaneous colour contrast.

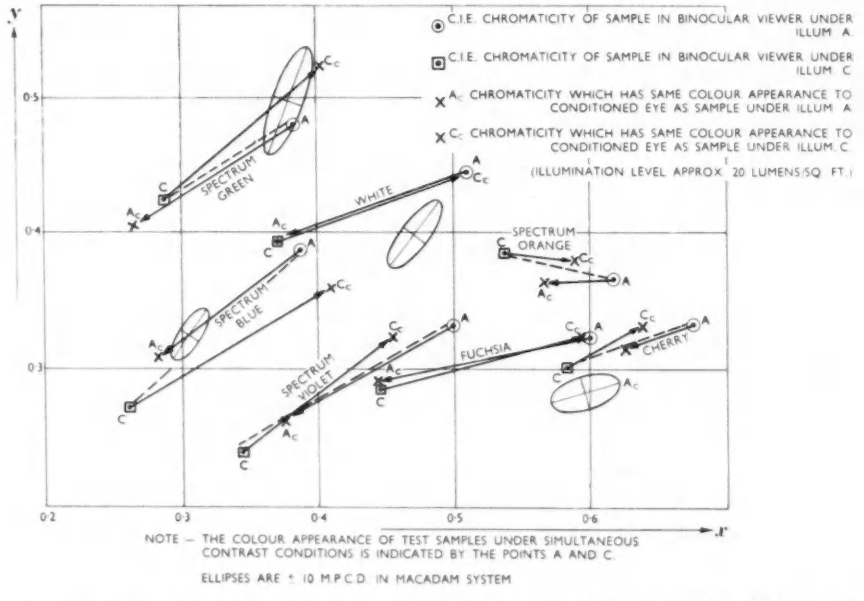
y
x
0·5
0·4
0·3
0·2
0·3
0·4
0·5
0·6
C.I.E. CHROMATICITY OF SAMPLE IN BINOCULAR VIEWER UNDER ILLUM. A
C.I.E. CHROMATICITY OF SAMPLE IN BINOCULAR VIEWER UNDER ILLUM. C
A_c CHROMATICITY WHICH HAS SAME COLOUR APPEARANCE TO CONDITIONED EYE AS SAMPLE UNDER ILLUM. A
C_c CHROMATICITY WHICH HAS SAME COLOUR APPEARANCE TO CONDITIONED EYE AS SAMPLE UNDER ILLUM. C
(ILLUMINATION LEVEL APPROX. 20 LUMENS/SQ. FT.)
SPECTRUM GREEN
WHITE
SPECTRUM ORANGE
SPECTRUM BLUE
FUCHSIA
CHERRY
SPECTRUM VIOLET
NOTE — THE COLOUR APPEARANCE OF TEST SAMPLES UNDER SIMULTANEOUS CONTRAST CONDITIONS IS INDICATED BY THE POINTS A AND C.
ELLIPSES ARE ± 10 M.P.C.D. IN MACADAM SYSTEM

Fig. 4.—Chromaticity diagram showing change of appearance of coloured samples due to change of conditioning from daylight Sc (6,500 degs. K.) to tungsten light S_A (2,850 degs. K).

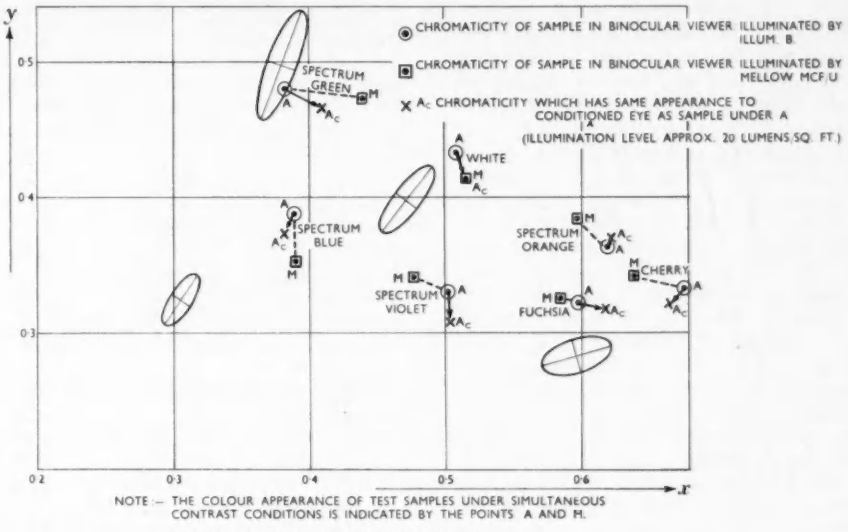

Fig. 5.—Chromaticity diagram showing change of appearance of coloured samples by change of conditioning from tungsten S_A to mellow MCF/U.

The results of these experiments, which confirm earlier work [2, 3, 4], are particularly interesting in that they show quantitatively the extent to which the eye compensates for the differences in the spectral distribution of daylight in its various phases and light from the full radiator illuminants such as tungsten filament lamps. This effect has long been appreciated qualitatively and appropriate compensation is made for this effect in colour photography. For example,

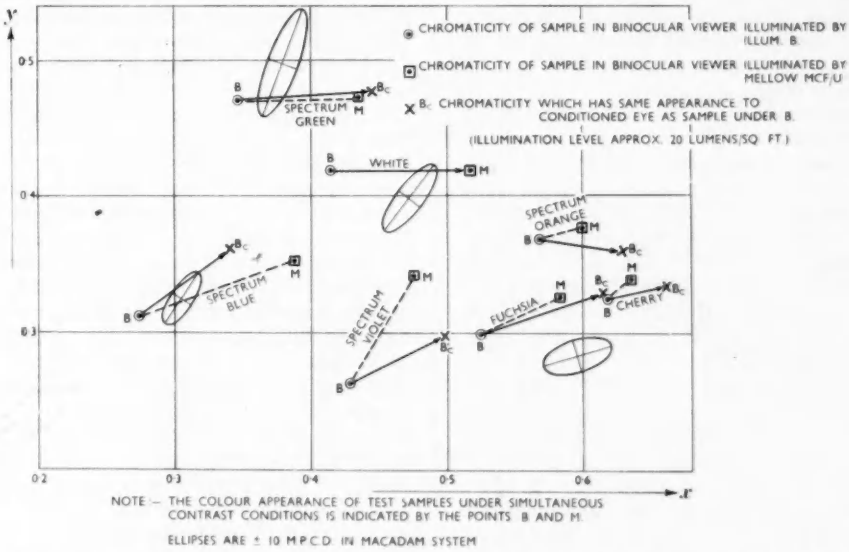

Fig. 6.—Chromaticity diagram showing change of appearance of coloured samples by change of conditioning from daylight S_B to mellow MCF/U.

it is common experience that if colour films of the type designed for daylight photography are used to make photographs of subjects illuminated by tungsten light, all the colours will appear excessively yellow as compared with the visual impressions of these same colours under tungsten light. If, in fact, an interior illuminated by tungsten filament lamps is viewed through a small aperture or window from outdoors, where the observer is conditioned to daylight, the indoor scene will also appear to be excessively yellow as compared with the visual impression when the observer is in the room and conditioned to light from tungsten filament lamps. Colour films for photography by tungsten light are, therefore, designed with a different colour balance to compensate for this subjective effect.

The subjective colour-rendering properties of fluorescent illuminants as compared with tungsten or artificial daylight are dealt with in the following section.

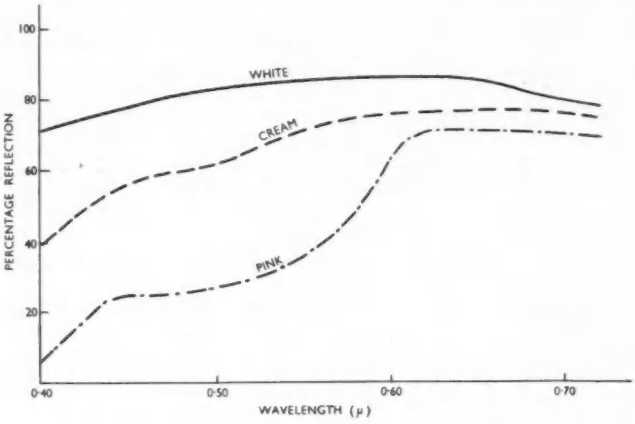

Fig. 7.—Spectral reflection curves of walls in binocular viewer.

(4) SUBJECTIVE COLOUR-RENDERING UNDER FLUORESCENT LAMPS.

Subjective comparisons by two observers have also been made between Standard Illuminants *A* and *B* and light from Mellow colour fluorescent tubular lamps.

The mean results of these measurements are plotted in figs. 5 and 6.

It will be seen from these figures that there is not the same measure of compensation between the fluorescent lamp and Standard Illuminant *A*, as is indicated in section 3 between Standard Illuminants *A* and *B*. This is particularly interesting in that the difference between the chromaticity of the Mellow fluorescent lamp and Standard Illuminant *A* is only about half of that between Standard Illuminants *A* and *B*. In "Colour and Lighting" (Part 2)[2] generally similar results were shown in the comparisons with daylight, natural, warm white and colour matching fluorescent lamps. Presumably the inability of the eye to compensate so completely in these cases is related to the different form of spectral distribution of fluorescent sources as compared with that of full radiators.

(5) QUALITATIVE SUBJECTIVE COMPARISONS OF FOODSTUFFS AND COMPLEXION.

Since the earliest days of the development of fluorescent lamps their colour-rendering properties have been judged qualitatively by simultaneous comparison of the manner in which coloured materials and objects, including food and the complexion, are rendered. The colour-rendering properties of fluorescent lamps as judged by the conditioned observer when viewing coloured test samples, have been indicated in section (4). It was not possible, however, to make objective measurements on the complexion and the more common foodstuffs, because only over very small areas were the colours uniform. It was decided, therefore, to carry out qualitative comparisons in the binocular viewer of food and the complexion under Standard Illuminants *A* and *B* and fluorescent light sources of the type used for social lighting.

For the purpose of these subjective preference tests on the complexion and food, the apparatus was used in a slightly different manner. Holes were arranged in the bottom corners of the doors to the two test compartments (figs. 1 and 2) so that the hands of the observer could be viewed in the respective compartments. Plates of similar samples of freshly prepared food and cups of tea were also placed in the two cabinets. The observer then conditioned himself, as in the previous experiments, and gave an opinion of the relative colour appearance of the two sets of

food and the hands. Thus, he was able to indicate the extent to which the colour-rendering of one source was different from that of the other source. These qualitative comparisons by eight observers confirmed the general trends found by the quantitative measurements detailed in section (4).

(6) EFFECT OF COLOURED DECORATIONS.

In the earlier published work[2] and observations recorded in sections 3, 4 and 5 of the present article, the walls of both compartments of the binocular viewing cabinet were white and the results obtained related to the subjective colour-rendering effects under different illuminants.

In most practical lighting installations the walls and furnishings will not be white and, therefore, it was thought useful to obtain some quantitative data on the extent to which the colour-rendering properties may be modified by the colour of the decorations and furnishings. To this end a series of measurements was made using the three sets of coloured panels in turn inside the binocular viewing cabinets. The spectral reflection curves of these panels are shown in fig. 7, and in Table 1 are given the chromaticity co-ordinates and luminance factors of the panels when illuminated directly by Standard Illuminant *A*. When these panels are in position in the viewing cabinets their chromaticity is modified by inter-reflections within the cabinet. The extent of this effect is shown by the measured chromaticity on the part of the panel on which the colour patch is normally mounted, and these values are included in Table 1. With each of these sets of detachable panels the chromaticities of the coloured test samples were measured in the binocular viewer illuminated by Standard Illuminant *A*. These results are shown plotted in fig. 8. It will be seen that the objective shifts in chromaticity due to the different coloured panels are comparable with those which occurred when using white walls and different light sources. This effect will vary quantitatively in different situations according to the light distribution of the lighting equipment used and the proportions of the room. The results quoted are illustrative of the effect, but the numerical result should be restricted to the conditions of this experiment.

Binocular judgments were also made comparing the subjective colour appearance of the coloured test samples in a white walled compartment with those in a pink walled compartment, Standard Illuminant *A* being used in both compartments. The results obtained in this manner by the conditioned observer are shown in fig. 9. It is probable that in this particular experiment the effect of simultaneous colour contrast was rather more marked than in the tests made with white walls and different illuminants. From fig. 9 it will be seen that the subjective changes in colour appearance of the test samples due to the coloured walls are comparable with those which occurred with white walls and different illuminants.

This quantitative evidence indicates that coloured decorations of a type which can occur in practice can effect the colour-rendering properties to an extent which should not be overlooked when designing a lighting installation.

TABLE 1.

CHROMATICITY CO-ORDINATES OF DETACHABLE PANELS. USED IN BINOCULAR VIEWER.

Colour of Wall	Luminance factor with Std. Illum. A.	C.I.E. CHROMATICITY CO-ORDINATES					
		Directly Illuminated by Tungsten at 2,850 degs. K., i.e. S_A Incident at 45 degs. to Normal			In Binocular Viewer Illuminated diffusely by Tungsten at 2,850 degs. K., i.e. S_A		
		x	y	z	x	y	z
White	83·5%	·452	·412	·136	·495	·430	·075
Cream	75%	·464	·416	·120	·515	·425	·060
Pink	47·5%	·528	·397	·075	·590	·385	·025

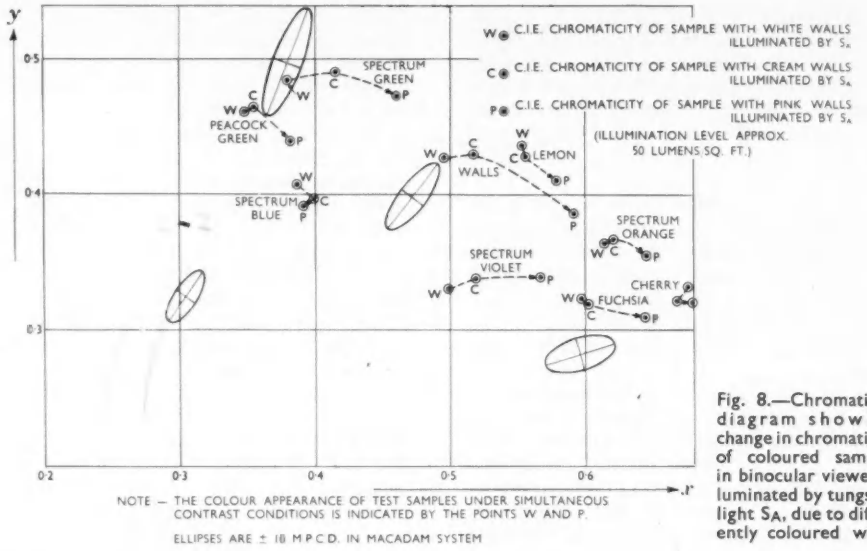

Fig. 8.—Chromaticity diagram showing change in chromaticity of coloured samples in binocular viewer illuminated by tungsten light S_A, due to differently coloured walls.

It is hoped to continue the investigations on the effects of coloured walls and furnishings by carrying out further tests in the binocular viewer with other colours of walls.

(7) OTHER FACTORS INFLUENCING SUBJECTIVE COLOUR-RENDERING.

The final assessment of the acceptability of any lighting and decoration scheme is likely to be a compromise between the first impression and the observed effect after the eye has become conditioned.

The relative importance of the first impression and that received after conditioning will depend on the particular circumstance and situation, and the following examples are quoted by way of illustration.

If the eye is in the dark adapted state when entering a room or hall, illuminated by lamps all of one type of spectral distribution, it is probable that a very tolerant view will be taken of the colour-rendering properties of the installation. This is because no simultaneous comparison can be made with any other source, nor is there a vivid colour memory of any other installation just prior to entering the room. In this case only long-term colour memory comes into play. During the war, under blackout conditions, it was quite a common experience to be dark-adapted when entering a lighted room, but now, in a town, such a situation is unlikely to occur although it is not uncommon in country districts.

When the observer is approaching a lighting installation from a lighted street at night, the colour-rendering properties of the street lighting installation will influence judgment although only to a small extent if the street lighting illumination level is low. The effect of street, shop and other outdoor lighting in conditioning the eye will be most important in lighted thoroughfares in cities, where the illumination level may be high and the illuminants may be tungsten filament lamps, high-pressure mercury, sodium, or fluorescent lamps. The high luminance of shop window displays may give rise to a marked conditioning effect.

In a lighting installation which is approached from daylight, colour memory will be very strong, at least during the first impression, and there will be a tendency to prefer colour-rendering properties approaching those of daylight.

Probably the situation in which it will be most difficult to ensure acceptable colour-rendering will be that in which a lighting installation is approached from another room, also artificially lighted but with an illuminant having quite different colour-rendering properties. This will be particularly difficult if one room can be seen from the other, so that simultaneous comparisons can be made of the respective colour-rendering properties. Such a situation should, therefore, be avoided if possible, and in any case an attempt should be made to provide entry from one to the other by a corridor in which the lighting is blended from the one class to the other.

It is the task of the lighting engineer to have in mind these various circumstances and to choose his light source accordingly; and to

choose also the colour decorations of the room in order to obtain an overall effect which will be the most acceptable æsthetically.

There is still another general point to be kept in mind which is related to the climate of the geographical location for which the lighting is being designed. For example, experience has shown that in tropical countries the colder light sources are much more popular than the warmer light sources whereas the reverse occurs in temperate or cold climates. Experience in temperate climates indicates that at least there is an optimum illumination level from full radiator sources depending on their colour temperature. For example, for a given condition of warmth of effect it has been shown that light of the same spectral distribution as sunlight loses the warmth normally associated with it, if it is used at very low illumination levels.

(8) CONCLUSIONS.

At the present stage of this investigation certain general conclusions can be drawn which may prove useful to the lighting engineer. These may be summarised as follows :

The factors enumerated below all contribute to the judgment of the extent to which colour-rendering is acceptable and must, therefore, be considered in respect of the overall effect of a lighting installation.

(*i*) Class of task to be performed in the installation. For example, the lighting may be required for an industrial task or for social purposes.

(*ii*) Colour and spectral distribution of the light source. The latter is expressed in abridged form by the relative luminance in eight internationally agreed spectral bands.

(*iii*) Illumination and luminance levels.

(*iv*) Colour and spectral reflection of the decorations and effects of simultaneous colour contrast.

(*v*) Conditioning of the observer prior to entering and while in the installation.

(*vi*) Simultaneous comparison of the lighting installation with that in adjacent rooms.

(*vii*) Climatic background.

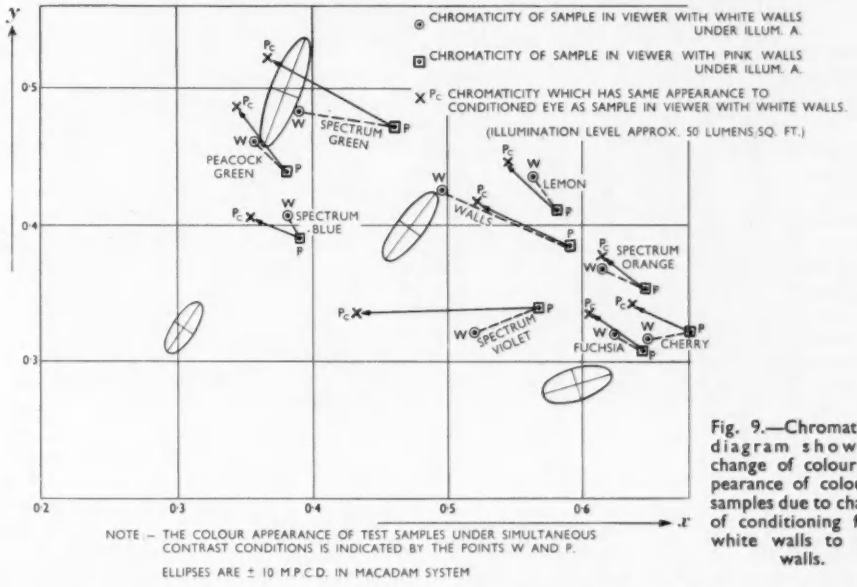

Fig. 9.—Chromaticity diagram showing change of colour appearance of coloured samples due to change of conditioning from white walls to pink walls.

The form and magnitude of some of the effects enumerated above are indicated in the diagrams referred to in the text. All the quantitative measurements carried out on the binocular viewing apparatus relate to fields of view of the proportions detailed in the paper. The magnitude of the different conditioning effects, however, may be affected by alteration of these proportions. Considerably more data would be required to form a basis for complete design calculations to allow for all the various controlling factors.

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The Application of Vibration to Industrial Processes

By A. G. D. SWIFT, B.Sc.

Fraser & Chalmers Engineering Works.

Vibration is usually considered to be an evil associated with all machinery, which has to be eliminated so far as possible.

Properly applied, however, vibration can provide a most convenient means of drive, and in many instances it is becoming increasingly preferred to usual mechanical methods.

Some industrial uses of this type of drive are described here, and these give an indication of the widespread application of vibratory equipment.

INTRODUCTION.

THE application of vibration for useful industrial purposes has made considerable progress during recent years, and is now being successfully applied in almost all industries in the processing and bulk handling of material, ranging from powder to the largest run-of-quarry material, from metal swarf to steel castings, and from coins to foodstuffs.

Fraser & Chalmers "Sherwen" electro-magnetically-operated vibrating equipment, entirely British in conception, design and manufacture, is of particular importance in this sphere, the range of machines including feeders, conveyors, screens, foundry shake-outs, vibrating tables, bunker vibrators, coolers, dryers, elevators, and machines designed for specialised applications.

The Sherwen vibrator was first developed as a D.C. operated machine and applied originally to concentrating tables, which had hitherto employed a mechanical head motion, involving complicated moving parts to produce the type of movement required for the concentration and separation of mineral ores.

The principle of operation was that of a simple electric bell on a large scale, and the pulsating movement of the armature was transferred to the table deck. The frequency could be varied from 300 to 800 vibrations a minute, and the amplitude was adjustable up to $\frac{1}{2}$ in. stroke. The same movement was applied to screens with considerable success, particularly in the field of fine screening.

The adoption of A.C. has made D.C. equipment nearly obsolete, and vibrators are now almost entirely A.C. operated.

SHERWEN A.C. VIBRATORS.

MECHANICAL & ELECTRICAL CONSIDERATIONS.

The Sherwen A.C. vibrator can be considered, basically, as two masses connected together by a spring system and excited by a pulsating force.

It can be shown that such a system has a natural frequency of vibration which is a function of the weight of the two masses, and of the stiffness of the spring system. Thus, an arrangement of springs can be so chosen that the natural frequency of the whole system has a predetermined value.

The source of the exciting force is an electromagnet, with the laminated armature attached to one of the masses, and the laminated core, with its associated coils, to the other, the two sets of laminations being separated by an air-gap. On applying a source of A.C. to the electromagnet the system is caused to vibrate at the same frequency as that of the supply.

If the natural frequency of the system can be made identical with that of the supply frequency, a condition of resonance is set up, and the maximum amplitude is obtained, accompanied by the minimum consumption of power under the given conditions.

It is convenient to use the 50 cycle national Grid as the source of A.C. supply for the electromagnet, giving 6,000 impulses per minute, and to make the natural frequency of the system 6,000 vibrations per minute, thus providing the necessary conditions for resonance. At this speed the vibrator becomes rather sensitive to

supply-frequency variation, and for this reason, and other mechanical considerations, it is generally restricted to small feeders.

To overcome this difficulty, use is made of the Sherwen principle of introducing a half-wave rectifier into the circuit. By eliminating one half of the A.C. wave the effective impulses to the electromagnet are reduced from 6,000 per minute to 3,000, and the resulting amplitude is considerably increased. The amplitude is controlled usually by means of a variable resistance in series with the vibrator coils, or by a variable transformer.

An alternative to half-wave rectification is D.C. injection, in which an alternating current, on which is impressed a D.C. component, is fed to the coils. The effect of this is to displace the zero line of the A.C. wave, which results in a series of impulses at 50 cycles per second, similar to that obtained with half-wave rectification.

In practice the two theoretical masses are replaced respectively by:

(*a*) A screen frame, feeder trough, table, or that part of the machine on which the material is to be handled or processed. This is generally of mild-steel construction although specialised applications may require the use of stainless steel, copper, aluminium, and so forth.

(*b*) A heavy cast-iron vibrator body, or an undercarriage of fabricated steel or cast-iron construction.

The spring system is either a battery of coil-springs, of which a large range of strengths is available, leaf springs, or a combination of both.

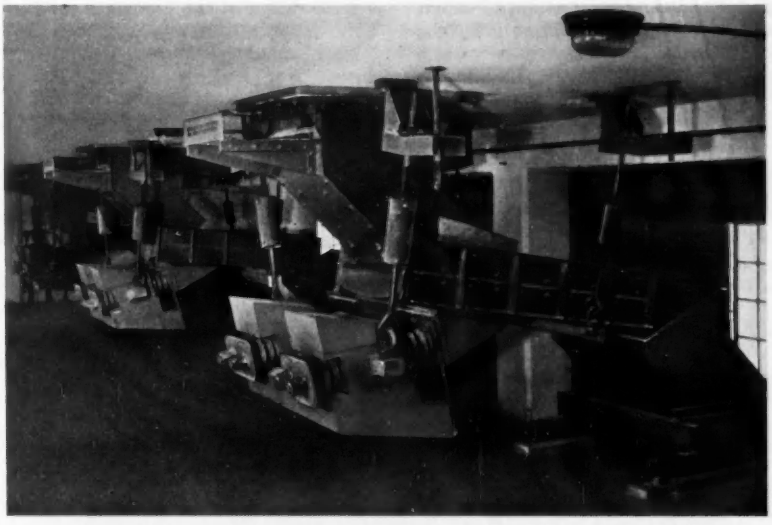


Fig. 1.—Three 24 ft. by 5 ft. Sherwen feeders, each handling 125 tons/hour of —2½-in. limestone, in a quarry of White's South African Portland Cement Company.

In the case of coil springs, these are so chosen that, with an initial compression, the natural frequency of the machine approximates to that of the supply. By increasing, or decreasing the compression, the natural frequency can be increased or decreased, within limits, so that the resonance condition can be obtained.

Similarly, a system of leaf springs varying in number, thickness and shape can be built up so that the machine can be tuned to resonance.

At the resonance point, however, unstable conditions are set up and the vibration is liable to be affected by load. The normal practice, therefore, is for the natural frequency to be set somewhat higher than that of the supply.

Variation in vibration due to the present temporary power cuts is stabilised by increasing the power input, and tuning the machine several cycles high.

As the circuit is mostly inductive, and complicated by half-wave rectification, the power factor is low. This is of the order of 0·3 and, due to the circuit characteristics, cannot be increased above 0·6 by normal correction

methods. Low current consumption, compared with that of mechanical vibrators, has, so far, not made correction worth while.

Normal air-gap setting for half-wave machines is ·055 in. which gives a maximum stroke on the trough or screen frame of the order of $\frac{1}{16}$ in., and for straight A.C. machines this is reduced to about ·025 in. giving a stroke of about ·02 in.

In general, machines can be arranged either for floor-mounting, or suspension, but no special foundations or fixing devices are necessary. The transmission of vibration to the building or structure, however, must be prevented. Floor-mounted machines are, therefore, supported on flexible rubber, or spring feet, and suspended machines have a vibration absorbing unit incorporated in the suspension rods. Thus, vibration is confined within the machine, and the structure need be designed to carry only the dead weight of the equipment.

The absence of moving parts in frictional contact makes replacements and maintenance extremely small, and this, coupled with the low power consumption, ease of control and cleanliness, gives considerable advantages over equivalent mechanical equipment.

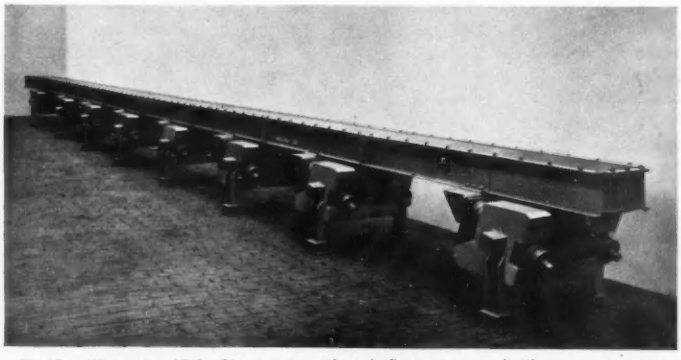


Fig. 2.—10 in. by 48 ft. Sherwen, enclosed, floor mounted vibro-conveyor to handle 10 tons/hour of dusty crushed stone and sand for Chamotte Unie N.V., Geldermalsen, Holland.

FEEDERS AND CONVEYORS.

The controlled movement of bulk material into, or out of, individual component machines of a plant, whether continuous or intermittent, implies the use of a feeding device. By applying vibration at an angle to a trough material can be made to move along it, and this feature forms the basic principle of feeding by vibration, which is the most widespread application of Sherwen vibrators.

The line of action of the vibration is generally at 20° to the trough, and the movement can be considered as being made up of two components, parallel and perpendicular, respectively, to the trough. On the forward, or conveying, stroke the material is carried forward by the " parallel component " and upward by the " perpendicular component." On the return stroke, as the acceleration of the trough is greater than " g ", the material does not return with it, but falls freely under gravity until it is intercepted at a point further along the trough by the next conveying stroke, i.e. the trough, in effect, slides back from beneath the material. Thus, the material moves in a rapid succession of small hops in a forward direction, which, due to the smallness of the amplitude, gives the appearance of a continuous flowing stream. As the material is in " semi-suspension ", a remarkably low rate of wear of the trough is experienced, which makes this type of feeder very suitable for abrasive materials such as sinter, carborundum, or coke.

Standard feeders may be fitted with one or more vibrators, either above or below the trough, according to the duty required and to the site conditions, and the trough may be open or enclosed, tubular, or jacketed for heating or cooling purposes.

A large range of standard feeders is available varying in size at present from 12 in. wide by 3 ft. long to 5 ft. wide by 14 ft. long.

The capacity depends on the characteristics of the material and the condition under which it is handled. A 12 in. by 3 ft. feeder fitted with a single light duty vibrator is capable of handling 25 tons per hour of small coal with a power

consumption of 500 watts, and a 5 ft. by 14 ft. feeder fitted with triple heavy duty vibrator will handle well over 600 tons per hour of the largest run-of-mine coal with a power consumption of 3·5 kW. Fig. 1 shows three 24 ft. by 5 ft. Sherwen feeders in a quarry of White's South African Portland Cement Company.

Most materials in granular, or particle, form are capable of being conveyed, but the presence of moisture, and stickiness considerably affect the capacity which may be expected from a given machine. Particularly difficult to handle are those fine, dry powders which entrain air, such as cement or hydrated lime, and which behave more like a fluid than a collection of discrete particles.

One of the more impressive feeder installations is at the National Coal Board's Thoresby Colliery, where two 5 ft. by 14 ft. heavy duty Sherwen feeders are each handling the whole output of the pit of run-of-mine coal up to 36 in. cube at the rate of 600 tons per hour. One feeder is at the pit bottom feeding the skip hoist, and the other is at the surface taking the coal from the skip discharge and feeding it to a conveyor. Each feeder has handled well over a million tons to date without any appreciable wear on the trough.

The ease with which the rate of feed can be controlled makes this type of feeder ideally suited to batch-weighing. The feeder is automatically controlled by the weigher mechanism and feeds at full capacity for about 95 per cent of the required weight. The remaining make-up weight is at a dribble-feed rate, and high accuracy is possible. In an installation in which nails are being weighed automatically into sacks, it is possible to obtain 1 cwt. batches accurate to a few nails.

Small capacity feeders used mainly for introducing subsidiary materials, at a controlled rate, into the main stream, are of a different design and are generally operated on straight A.C. The trough is mounted on an undercarriage by leaf springs set at the conveying angle of 20°. These control the movement to give the necessary parallel and perpendicular components. Sizes vary from a 3½ in. by 17 in. laboratory feeder to 12 in. by 4 ft. which is capable of handling up to 10,000 lbs./hour.

Vibrating conveyors are similar in all respects to feeders, with the trough length increased to suit, and with vibrator units fitted at approximately 5 ft. spacing. A 10 in. by 48 ft. vibro-conveyor is seen in fig. 2.

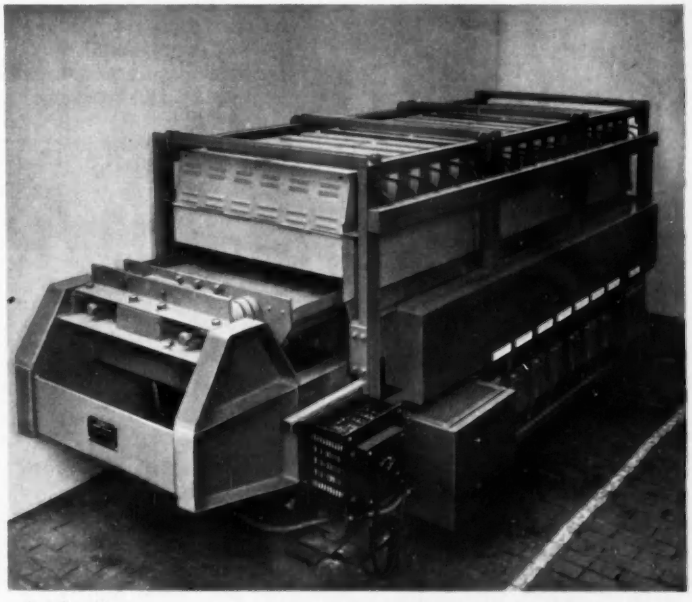


Fig. 3.—Continuous heating plant for drying 500 lbs./hour of diamond concentrates, comprising a 3 ft. by 10 ft. Sherwen vibro-conveyor, 27 kW infra-red installation and 9·75 kW auxiliary tubular heaters for Williamson Diamonds, Ltd., Tanganyika.

From capital cost considerations a vibro-conveyor compares unfavourably with a belt conveyor for ordinary materials, due to the large number of vibrators which may be required. It is, however, particularly suited to the handling of hot or abrasive materials, and also, due to the ease with which it can be enclosed, of toxic and chemical products, where contamination has to be eliminated and disagreeable fumes controlled, and of foodstuffs, where cleanliness is a first consideration.

Small capacity conveyors of the undercarriage type are made up to 4 ft. wide by 20 ft. long, and are largely used, in conjunction with suitable heating equipment, for continuous-process, heating and drying of granular or powdered materials, where full use can be made of the instantaneous, accurate control of feed rate.

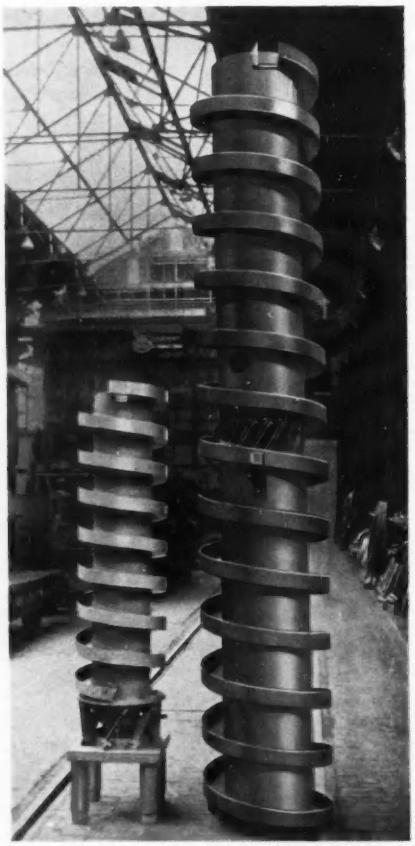


Fig. 4.—Two types of Sherwen-spiral elevator : (*left*) 3 in. wide trough by 5 ft. lift; (*right*) 4 in. wide trough by 12 ft. lift.

Numerous installations have been built, in collaboration with the Process Heating Department, where such diverse materials as sawdust, plastic granules and diamond concentrates are heated by banks of infra-red lamps (fig. 3).

It is possible to convey uphill, but the angle is limited to about 10°. This is insufficient to make elevating by the normal type of vibro-conveyor a practical proposition.

A new development, however, has been the Sherwen spiral elevator, in which a trough, in the form of a helix, is coiled round a central supporting tube at a mean angle of 10°. This is supported on a floor mounted vibrator by a series of inclined leaf springs radially disposed round the base of the trough unit (fig. 4).

The action of the vibration causes the trough to vibrate vertically and at the same time, the springs impart a rotary component to it. The resulting movement gives a true conveying action to every part of the trough and enables material to be carried up hill.

A further development is the replacement of the vibrator body by a second spiral trough section, the two sections now reacting one against the other. The spring and electrical systems are centrally disposed and the bottom section feeds into the top, as the two, being out of phase, cannot be rigidly connected. The advantage of this arrangement is that a given spring and electrical system can handle a trough twice the height of the previous design.

These elevators are at present only applicable to light duties, and are being used to a large ex-

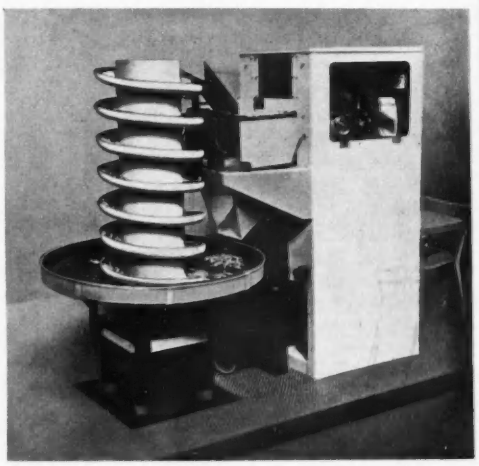


Fig. 5.—Sweet weighing machine fed by a Sherwen spiral elevator and incorporating two small Sherwen feeders to give the main and dribble feeds to the weigher mechanism.

tent in feeding sweets and similar commodities to batch weighers and packaging machines (fig. 5).

The comparatively long distance the material has to travel to reach a given height is the basis of a spiral elevator cooler now being made for plastics, where cooling air-streams are passed under low pressure from the central supporting tube to the material at a number of points along the trough. Heating and drying can also be carried out by the use of heater-elements introduced into the supporting tube, and experiments have proved most satisfactory.

Since the introduction of this elevator considerable interest has been aroused by its adaptability for carrying out processing while the material is being elevated, and by the very small floor area required compared with orthodox elevators.

Another recent development is the Sherwen reversible vibro-conveyor. From what has already been said, it will be seen that the forward direction of flow depends on the upward movement occurring on the forward stroke. If the upward movement can be developed on the return stroke, then the flow will be in the opposite direction. The amplitudes of two vibrators at right angles can be so arranged that the resultant is at the true conveying angle. By attaching two such vibrators to a trough, each separately controlled through its own rectifier and rheostat, providing respectively the 'parallel' and 'perpendicular' conveying components, it is possible to arrange for either of the above reversing conditions. A changeover switch, for reversing the polarity of the rectifier of one of the vibrators, enables it to be energised by either half of the A.C. wave. Thus, in one case, both vibrators are energised from the same half-wave and the forward movement is in phase with the upward movement giving a forward flow. In the other case, the vibrators are alternately energised from opposite half-waves which are 180° out of phase. The return movement is, therefore, in phase with the upward movement and the flow is reversed.

Material is fed to the centre of the trough and can be discharged at either end at will, or at intermediate take-off points. One of its uses will be in passing material from a single belt conveyor to either of two alternative following conveyors, eliminating the present complicated chute work, and flopper-gate gear. Reduction in building heights will be possible at the transfer points, and the required direction of flow will be by remote control, and not, as at present, by manual operation.

A new type of vibro-conveyor at present undergoing tests is novel in respect of both the spring system and the vibrator drive. It is so designed that any number of standard lengths, each with its own self-contained power-unit and spring system, can be joined together in a simple manner to form a continuous conveyor of the required length. A further novel feature is the provision of curved sections which will make it possible to change the direction of the conveyor. Thus a combination of curved and straight sections will enable a very versatile conveying system to be built up.

SCREENS.

The main function of a screen is to produce

Fig. 6.—3 ft. by 8 ft. Sherwen double deck screen handling 25 ton/hour crushed slag and screening at $\frac{1}{4}$ in. and $\frac{1}{16}$ in. at the Concrete Works of Dorman Long & Co., Ltd., Middlesbrough.

from bulk material one or more products graded in size according to whether or not the constituent particles pass through, or are rejected by, given apertures.

By passing the material over a vibrating woven-wire mesh cloth efficient separation at the aperture size can be effected. The vibration causes segregation of the particles, and the smaller sizes fall to the bottom of the bed of material for acceptance or rejection by the apertures. Vibrating screens of the electromagnetic type are in general use for screening from 1 in. square apertures down to 60 mesh (·01 in.), which, in the complicated problem of screening, covers the most difficult size range. Above 1 in. the vibration is insufficient to dislodge near-aperture size pieces caught in the mesh, and below 60 mesh the thin wire required for the screen-cloth is subject to failure by vibration fatigue.

The standard type of Sherwen screen consists of a mild steel frame, having one or more decks each comprising a tensioned, woven-wire screen-cloth of the required aperture size (fig. 7). The frame is vibrated normally to the screen-cloth by an overhead vibrator, and is installed at 20°-40° to the horizontal, depending on the duty, to maintain the flow of material which is fed evenly to it. By inclining the vibrator at an angle to the screen cloth a conveying action is set up in the material and enables the head-room to be reduced as the machine can be operated at a flat angle. Screens are also used for the de-watering of slurries, in which there is a high water-to-solids ratio, and scalping, and de-breezing, in which high screening efficiency is not necessarily required.

For de-watering, wedge-wire screen cloths are used having apertures ranging from ¼-1 mm., and screen conveyors of this type, operating horizontally, are incorporated in Fraser & Chalmers' heavy media separation plants for recovery of the heavy medium.

The ore is separated from the gangue by sink-and-float methods in a suspension of ferro-silicon in water. The float product (gangue) and the sink product (ore) discharge respectively from the separation cone on to drainage screens where the majority of the valuable medium is drained off for further use. The products then pass to washing screens where the adhering medium is washed off by water sprays and returned to the system.

A 100 ton/hour heavy media separation plant, now being built for The African Manganese Co., incorporates three 3 ft. by 10 ft. "float" draining and washing screens handling a feed of 40 tons/hour of gangue and 160 tons/hour of water, and three 5 ft. by 10 ft. "sink" draining and washing screens handling a feed of 60 tons/hour manganese ore and 240 tons/hour of water, the recovery being at ½ mm.

Fig. 7.—An installation at S. A. John Cockerill, Seraing, Belgium, comprising eight 5 ft. by 8 ft. Sherwen screen feeders, each handling 50 ton/hour large coke in conjunction with weighers and removing the −½ in. breeze.

Scalping screens, or grizzlies, are usually installed between a crusher and its associated feeder to remove from the feed all material below crusher-product size. These are invariably heavy duty machines with the screen-cloth replaced by heavy section, self-relieving, grizzly bars set at the crusher-product size.

A 40 in. wide by 4 ft. long Sherwen grizzly-screen at a quarry in Somerset is handling 70 tons/hour of limestone containing lumps up to 24 in. cube to a 36 in. by 24 in. breaker set for a 3 in. product, and relieves the crusher from dealing with the −3 in. material already in the feed.

It is often convenient to combine the separate feeder and grizzly into a single feeder-grizzly unit. The discharge end of the feeder trough in this case is formed of a section of self-relieving grizzly-bars, but has the disadvantage that the two distinct functions cannot be separately controlled.

The largest Sherwen feeder-grizzly yet made is 4 ft. 9 in. wide by 10 ft. long to handle 200 tons/hour of −36 in. cube limestone, and removes the −3 in. material. This machine is shortly to be installed in the primary crushing section of the new limestone crushing plant of Beswick's Lime Works, Buxton.

In many processes it is necessary to remove from a finished, sized product fines caused by storage degradation and breakage in handling. For this duty screen-feeders are used, in which the feed-end of the screen acts as a feeder, and the discharge-end only is arranged for screening. By this means, a controlled feed can be efficiently de-breezed. A typical example of this type of equipment is that at the new blast furnace installation of S. A. John Cockerill, Seraing, Belgium, where a group of eight 5 ft. by 8 ft. Sherwen screen-feeders, each capable of handling 50 tons/hour of large coke, removes the −½ in. coke breeze (fig. 7). The machines, controlled by weighers, deliver accurately weighed batches of the de-breezed coke to a belt conveyor system which feeds directly to the blast furnaces.

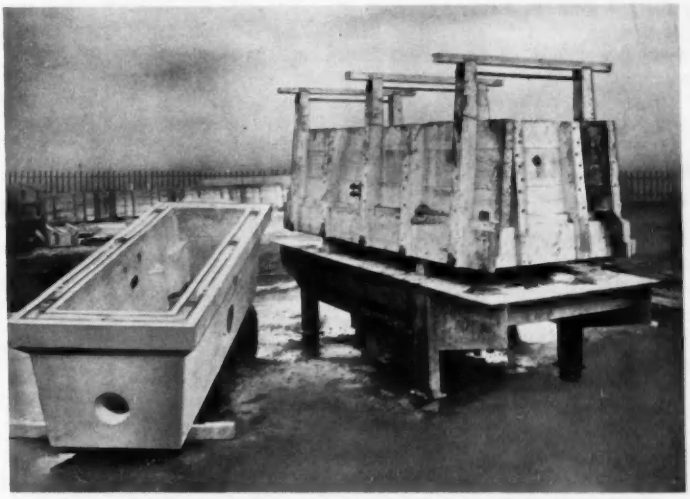


Fig. 8.—A 4 ft. by 10 ft. Sherwen concrete mould table with mould in position and finished casting alongside, at Kinnear, Moodie & Co., Ltd., Ashford, Middlesex.

The removal of foreign matter from a finished product is also an important screen function. An instance of this is in the cement industry, both at home and abroad, where a considerable number of Sherwen screens has been supplied for the final elimination of any extraneous matter such as paper, string, tramp iron, etc., from the finished cement prior to packing.

Another interesting example of this is in the sugar-growing areas where Sherwen screens are used to separate crushed cane fibre from the sugar liquor at the rate of 300 gallons per minute. Special 6 ft. wide by 6 ft. long screens, fitted with ·0125 in. aperture stainless-steel cloths, are used, with provision for cleaning down by steam jets.

VIBRATING TABLES.

The demand for reinforced concrete of ever-increasing strengths has led to the almost universal use of vibration for consolidating the concrete mix. The Sherwen table used for the manufac-

ture of pre-cast concrete units was originally developed for the production of concrete tunnel segments for the deep air-raid shelters prior to the last war.

A fabricated steel table varying in size from 12 in. square to 4 ft. by 10 ft. and in capacity from ½ cwt. to 35 cwt. is fitted with a vibrator unit having a vertical line of action. The rapid linear vibration, evenly distributed, sets up particle agitation in the mix and consolidates it by expelling the entrapped air and surplus water (fig. 8). The time of vibration depends largely on the amount of moisture present, a dry mix taking longer than a wet one. For a one-ton casting of dry "zero slump" concrete, consolidating time is about one minute.

A desirable feature, not easily attained with mechanical tables, is the instantaneous control of vibration amplitude. By a gradual controlled reduction of the vibration to zero after the consolidating period, the strongest casting is obtained.

The consolidating effect is applied to the packing of containers with powders and granular material. The settling together of the particles results in a smaller container being required for a given quantity of material and up to 30 per cent reduction in volume may be achieved, depending on the material. By applying the vibration at a slight angle to the table packing and conveying of the container can be carried on at the same time.

A more modern application is in the lost-wax method of precision casting of metals. An accurate wax pattern is immersed in a liquid suspension of fine powders. Gentle, even vibration consolidates the powder into a homogeneous mass round the pattern, eliminates voids and expels the surplus liquid which is drained off. The resulting mould, after the wax has been melted out, gives a casting accurate to ·001 in.

Increasing use of this principle is made in the production of gas turbine blades, where the special heat-resisting metals present a difficult problem in machining, but which can be cast comparatively easily with considerable accuracy.

FOUNDRY SHAKE-OUTS.

A logical development from the vibrating table has been for the foundry trade, where Sherwen foundry shake-outs make use of the rapid, pulling-down action of high-frequency vibration for shaking out mould boxes.

A mild-steel grid, incorporating a bar screen, or perforated plate, for breaking up and screening the knocked-out sand, is spring-connected to a cast-iron undercarriage, which is open in the centre to allow the knocked-out sand to pass through to a reclaiming conveyor. The electrics are totally-enclosed to exclude hot, loose sand and iron dust from the coils and air-gap (fig. 9). The boxes are placed on the grid and the vibration breaks away the sand and frees the casting. Small boxes up to 5 cwt. can be handled at the rate of 120 per hour, the knocking-out time being measured in seconds, but larger boxes up to 2 tons may require as long as a minute, depending on the type of box, shape of casting, and quality of sand.

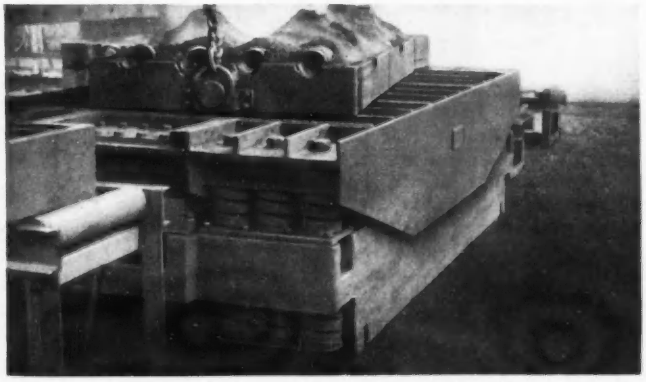


Fig. 9.—A 4 ft. 6 in. by 6 ft. Sherwen foundry shake-out handling cast-iron pipe.

Since the original shake-out, designed for a load of 10 cwts., was installed in 1946 in the foundry at the Witton Works, a large number have been made, ranging in size from 2 ft. 6 in. by 3 ft. 6 in. for 3 cwt. boxes, to 5 ft. 6 in. by 8 ft. for 2-ton boxes. For larger castings a number of shake-outs, which necessarily vibrate in synchronism, can be ganged together as a single unit. A number of machines is being supplied to Stanton Ironworks, comprising three standard 4 ft. 6 in. by 6 ft. shake-outs bolted together, giving a grid area of 6 ft. by 13 ft. 6 in., to handle 6 tons.

A recent interesting development has been a shake-out conveyor for use in highly-mechanised, continuous process foundries, where boxes are generally all of one size (fig. 10).

This is similar to a floor-mounted feeder modified to handle mould boxes, which are automatically fed on to guide rails on the top flanges of the trough. The vibration conveys the boxes

along the shake-out and at the same time knocks out the casting and the sand. The castings fall on to a series of grids fitted in the trough along which they are conveyed, and are finally discharged on to a cooling conveyor. The sand passes through the grids to a reclaiming conveyor, and the empty boxes are discharged from the end of the trough to a conveyor for return to the moulding machines. The sequence of operations is entirely automatic and has proved highly successful. Three of these machines have been installed at the new British Railways mechanised foundry at Horwich, where sleeper chairs, and brake-blocks are produced at the rate of 30 tons per hour.

Provision can also be made for the shake-out to accept, automatically, boxes of varying sizes, within limits.

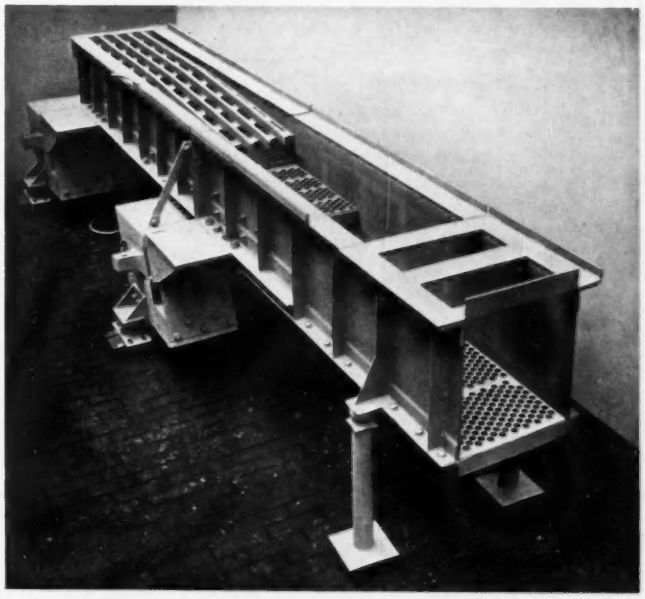


Fig. 10.—18 in. by 14 ft. Sherwen foundry shake-out conveyor.

BUNKER VIBRATORS.

A range of small vibrating units is available for maintaining the flow of sticky or difficult materials in bunkers or chutes. The unit is bolted directly to a steel bunker at the point where holding-up occurs, or near the outlet, and agitation set up in the material keeps it moving.

For concrete bunkers, the unit is totally enclosed in a mild steel box fitted with a series of agitating arms, and is suspended internally in the material near the outlet by a pipe up which the leads are carried.

The prohibiting of the dangerous practice of lowering men into coal bunkers at power stations for trimming purposes has made necessary some automatic trimming device. The success of an experimental vibrator of the internal type at Hams Hall 'B' Power Station has resulted in a large number of these units being supplied to B.E.A. stations for this duty.

CONCLUSION.

This brief and by no means comprehensive review of Sherwen vibrating equipment will give some insight into its potential application to ever-increasing industrial uses, of which the fringe only has yet been touched.

The reluctance with which industry in general has hitherto accepted new methods has now been largely overcome, so far as vibrating equipment is concerned, and acknowledgment of this should go to those concerns who have helped in development by installing prototype machines in their experimental stages, and without whom teething difficulties could not have been overcome or reliability established.

New ideas and applications are being continually investigated, but unfortunately their development for industrial use is largely governed by the demands of standard machine production on the available manufacturing facilities.

Aluminium Sheathed Cable

By B. O. ASHFORD, B.Sc., D.I.C., Pirelli-General Cable Works, Ltd
and
J. A. DONELAN and J. R. PENROSE, G.E.C. Research Laboratories.

INTRODUCTION.

DURING the seven years following the second World War the electric cable industry has been pursuing vigorously the development of techniques whereby aluminium can be used to replace the traditional lead as the sheathing material for underground power and communication cables. The Pirelli-General Cable Works, Limited and the Research Laboratories have now, after an intensive period of collaboration, brought to the stage of commercial production a method having outstanding advantages over others developed during this same period. The achievement may be summarised as follows : Aluminium sheathed cables having any of the standard types of dielectric can be produced in any lengths up to the maximum which it is convenient to handle, in diameters from about half-an-inch up to three inches. A feature of the manufacturing method permits a variation of the degree of flexibility of the cable ranging from that of the cold-drawn tubular aluminium sheath cable to that of the traditional lead sheath type.

The following brief historical review of the immediate post-war position of that section of the cable industry for which metal sheathing is a vital component of its products, will explain the powerful incentive behind this vigorous programme of development.

The post-war shortage of virgin lead, resulting from reduced refinery output and new high

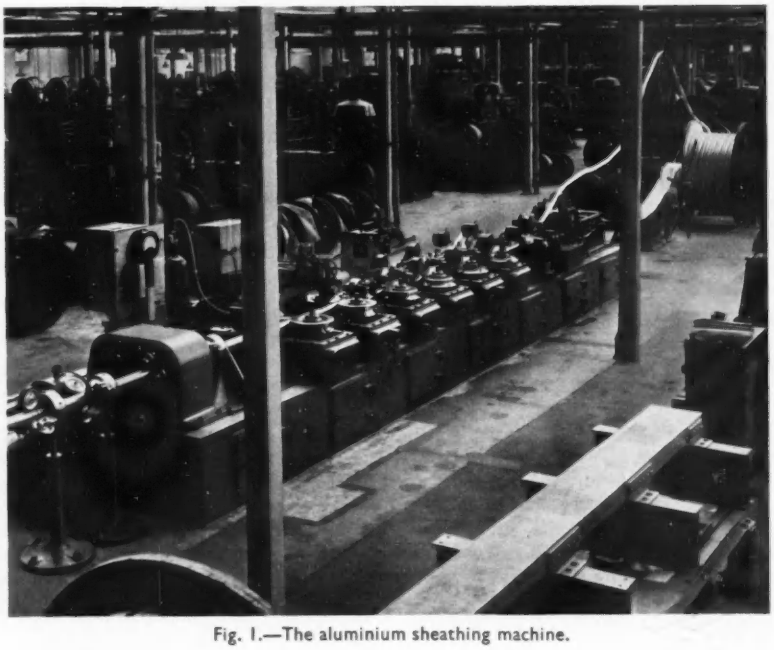


Fig. 1.—The aluminium sheathing machine.

priority demands, produced a state of affairs in which the output of the cable industry was limited almost entirely by the amount of lead available to it, other essential raw materials being in relatively free supply, while manufacturing plant capacity was adequate. In 1946 there began a drive for substitutes embracing other metals, composites of metal and plastic, and even plastics of low moisture diffusivity used alone. It was learnt that during the war the Germans, in similar difficulties, had attempted that much effort was being expended on the development of methods which would circumvent the difficulties encountered in Germany, the most prominent of these being based upon :

1. Drawing insulated core into oversize pre-extruded tube followed by cold-sinking the latter down to the core diameter.
2. Longitudinal welding of strip formed into tube.
3. Extruding oversize pipe on to the cable core with simultaneous cold-reduction in tandem with the extrusion.

Fig. 2.—Tube forming rolls.

to modify lead sheath extrusion presses to take super-pure aluminium, the only alternative available to them, and that they claimed a considerable degree of success, the aluminium sheath produced having certain inherent advantages over lead sheaths. In 1947 a Government mission was sent to investigate the position in Germany, and were able to confirm that a few score miles of telephone cable had been sheathed by direct extrusion of super-pure aluminium, but that the optimism as to the future of the method shown by the designers of the specialised extrusion plant was not shared by the industry as a whole, and certainly not by potential users of the cable.

From 1949 onwards it was clear that in the United Kingdom aluminium had come to be regarded as an acceptable alternative to lead and

Method 2 was selected by Pirelli-General and The General Electric Company, the choice being influenced by :

(*a*) The success of the already well-established welded stainless steel cable sheath manufactured by Pirelli-General.

(*b*) The unique experience of the Research Laboratories in the development of automatic electric welding equipment.

(*c*) The freedom from the disadvantage of limitation of length to which all the extrusion methods were subject.

The welding technique employed made use of a previously patented twin-arc electrode and control system in conjunction with an inert gas shield.

ARGON ARC WELDED ALUMINIUM SHEATH.

The primary step in the manufacture of the Pirelli-General argon arc welded aluminium sheath is that of producing a longitudinal butt welded tube comparable in uniformity and soundness with extruded and drawn tubes. The plant in which this is achieved is described in the following section.

The need to space the welding heat zone away from the surface of the combustible cable core necessitates a secondary step in which the internal sheath-diameter-as-welded is brought down to that of the insulated core. Two methods, or rather two variations of the same method, are available for this (*a*) rolling down, and (*b*) corrugation.

(*a*) *Rolling down.* The plain cylindrical sheath emerging from the welding head is reduced in diameter without alteration of form or appreciable increase in length, the surplus metal being absorbed in uniform thickening of the wall.

(*b*) *Corrugation.* The effective internal diameter of the slightly oversize welded tubular sheath loosely enclosing the cable core is reduced by corrugation so that it just embraces the core. The resulting cable is remarkably flexible in the sense that it requires little effort to bend it and in that it withstands repeated bending on diameters appropriate to lead sheath cable without damage or undue distortion of the sheath. The bending performance is so good, even with a much lighter gauge of metal than is usual for normal tubular sheaths, that this method is recommended for all cables except those in which the dielectric design would not permit an internally corrugated sheath, and where bending diameter requirements are, in any case, unlikely to produce excessive sheath distortion.

An incidental advantage of the necessity to reduce the effective diameter after welding is that by variation of the depth of rolling-down, or corrugation, a single size of tube, as welded, provides for a range of cable core diameters, permitting an economic design of plant and accessories. The pitch, radius and range of depth of corrugations are graded in relation to the external diameter of the sheathed cable.

MANUFACTURE.

Surface Preparation and Forming.

Aluminium strip fed from a coil in a continuous length sufficient for the cable in hand is first passed through rotary shears which trim both edges, cutting the material to the exact width, and producing clean edges which are essential for satisfactory welding. The external surface of the sheath is cleaned by high-speed rotary scratch brushes and the material is then passed to the first horizontal forming rolls.

The cable core is inserted at this point and the

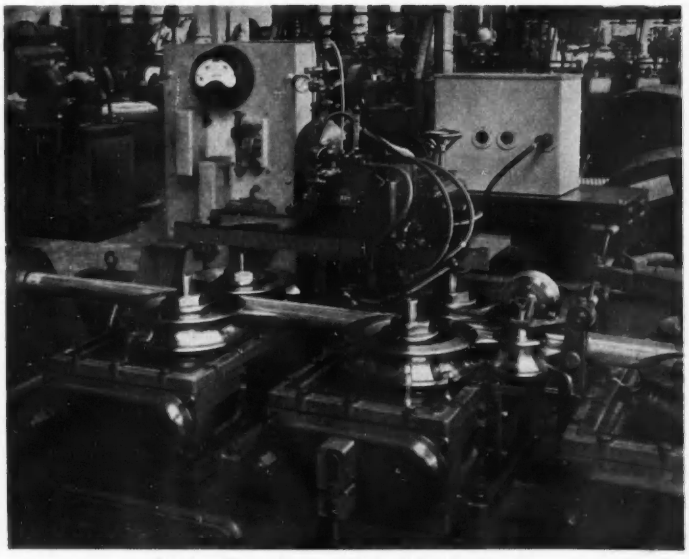


Fig. 3.—Tube closure rolls and welding unit.

sheath progressively closed round it by five subsequent forming rolls, the last stage also acting as the seam closure roll for welding. Fig. 1 gives a general view of the machine.

The design of forming rolls adopted is illustrated in fig. 2. This type of horizontal rolls controls and forms the strip without damage to the butting edges, the surfaces of which have been perfectly prepared for welding at the previous stage, and immediately after welding the sheathed cable passes through horizontal positioning rolls and torsion check rolls which correct any tendency for the sheath to rotate and so displace the weld seam in relation to the arc.

All the rolls except the last-mentioned are driven through gears from a common shaft and provide the necessary motive power for the passage through the forming, welding and corrugating heads.

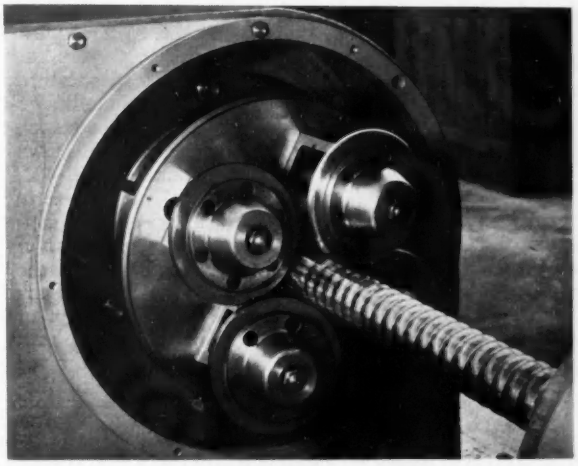


Fig. 4.—The corrugating head.

Welding.

The formed and closed strip passes under the argon arc welding torch which is mounted vertically above the closed sheath seam, and is attached to a compound slide which allows transverse movement for regulating the arc to the weld seam position, and longitudinal movement for advancing the torch along the seam for restarting the weld (fig. 3).

The G.E.C. twin-arc welding process was finally adopted as being capable of giving optimum weld contour and of allowing variation of width of weld to suit any particular conditions. This system of welding uses a twin-electrode argon arc welding torch fed from a three-to-two-phase Scott connected transformer and draws balanced current from the supply. A high-frequency spark discharge unit is included which serves to start the alternating current for welding. The use of this spark discharge allows the arc to be struck without the tungsten electrodes coming into contact with the work.

Protection of the Dielectric.

In order to avoid contact between the cable core and the bead of molten metal under the weld with resultant damage to the insulation and liberation of gases harmful to the weld, several methods of protection were investigated.

The one finally adopted employs a shaped metal shoe as a backing strip interposed between the sheath and core, which may be water-cooled, or used to supply inert gas to the underside of the weld.

Rolling Down.

Reduction of diameter by rolling down is achieved by passing the formed and welded tube through a planetary roll system incorporating four curved-tapered rolls of deep section driven at a fairly high speed. A useful range of cable diameters may be covered by a single size of tube as formed and welded.

Corrugating.

The alternative method of diameter reduction by corrugation is put into effect by substituting for the set of four tapered rolls a radiused indenting roll and three thrust-opposing rolls driven at a predetermined speed in accordance with the pitch of corrugation required. The corrugating head is illustrated in fig. 4.

Strip Joining.

Although aluminium strip is available commercially in continuous lengths adequate for most of the normal types of underground cable, complete freedom from limitation of production length in manufacture, and the ability to join random lengths of strip, are both extremely valuable assets.

The technique of cross-joining strip by welding was therefore worked out at an early stage of the development and follows the same general

principles as the welding of the longitudinal seam except that single-phase A.C. is used with a single tungsten electrode, the arc traversing the butting edges of the strip ends, which are cut obliquely so that opposite end portions do not coincide when the joined strip is formed into tube.

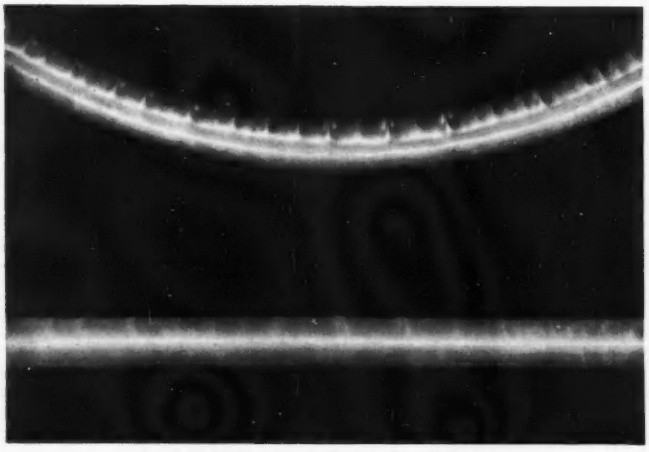


Fig. 5.—Rolled-down sheath after bend test.

The strength of the joint, which after peening is practically flush, is almost equal to that of the parent metal. The position of a joint is hardly distinguishable in a subsequently formed and welded tube.

MECHANICAL PERFORMANCE OF THE WELDED SHEATH.

Bending Tests.

(*a*) *Cylindrical type.* It is generally accepted that the bend test specified in British Standard No. 480:1942 (six bends on a drum of diameter 12D, D being the overall diameter of the cable) applied to a plain cylindrical aluminium sheathed cable produces sheath distortion such as might seriously injure the dielectric. Hence it has been agreed tentatively to increase the bend test diameter to 20D when testing such cables, and under these conditions the new welded cylindrical type of sheath manufactured by the rolling-down process behaves more satisfactorily than existing types of " drawn down " aluminium sheath. Fig. 5 shows a tested sample, subjected to three reverse bends at 20D, in the bent state and after re-straightening.

(*b*) *Corrugated type.* In formulating the design of the corrugated sheath the aim has been to equal or surpass the performance of lead sheathed cable in respect of ability to withstand repeated bends on the actual diameters laid down in British Standard No. 480: 1942. The relevant clause in this Standard is primarily concerned with the behaviour of the insulation on bending of the cable and does not make any reference to the condition of the metal sheath after the test, but it has been recognised in the course of this work that mechanical distortion of a metal sheath so much harder than the traditional lead sheath might cause injury to the insulation under the severe test conditions specified.

Hence it was decided that, after the appropriate unmodified bend test, the aluminium must not only be free from cracks but must show no excessive local distortion. The depth, radius and pitch of the corrugations are based on this requirement.

Fig. 6 illustrates the condition of a 1·6 in. diameter cable before and after performance of the B.S. 480 Bend Test (six bends on a drum of diameter 12D).

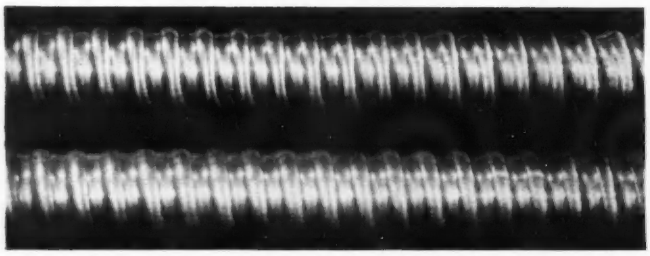


Fig. 6.—Corrugated sheath before and after bend test.

Weld Strength and Soundness.

The advanced designs of welding head and electrical system which have been previously described ensure standards of continuity and soundness in the weld comparable with those of an extruded sheath. Fig. 7 shows the contour and microstructure of a weld in transverse cross section. The central fusion zone of the weld, on account of its greater thickness, is stronger than the parent metal and the portions adjacent to it are only

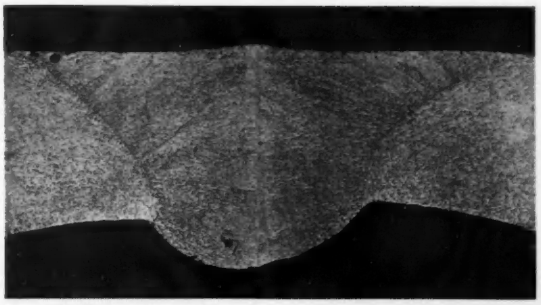
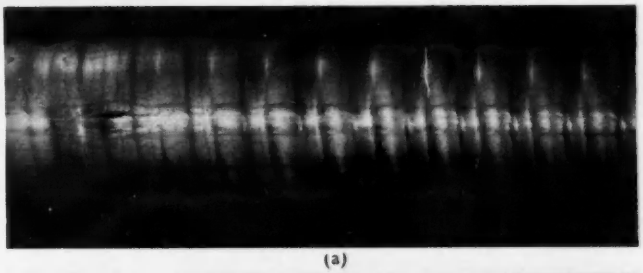


Fig. 7 (*above*).—Macrograph of transverse cross-section of weld (magnified eleven times).

slightly weaker than the remainder of the sheath wall. Hydraulic bursting tests at slow rates of strain may produce fracture at the weld boundary or at positions remote from the weld. Fig. 8a illustrates such a burst on a 2·7 in. diameter pipe of ·098 in. wall thickness, which required about one minute under a pressure of 890 lbs./sq. in. At 800 lbs. per sq. in. a similar sample did not fail in 500 hours ; when the pressure was raised to 900 lbs./sq. in. the burst occurred in the parent metal (fig. 8b).



(a)

(b)

Fig. 8 (*above*).—Bursting tests on corrugated sheath.

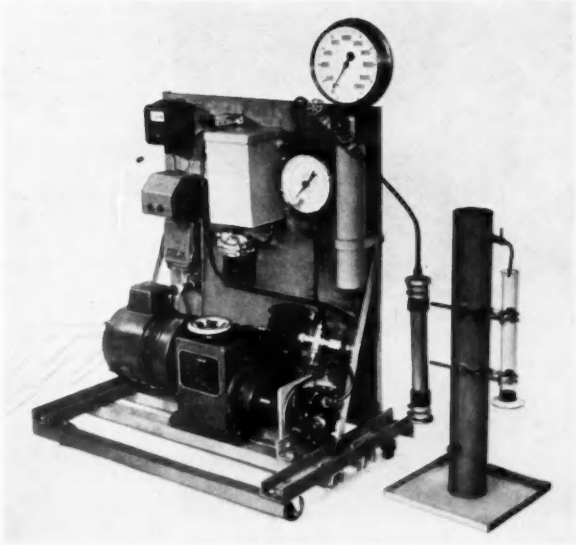


Fig. 9 (*left*).—Hydraulic test apparatus.

Hydraulic testing equipment designed and constructed at the Research Laboratories for the investigation of bursting characteristics over an extremely wide range of accurately adjustable speeds is illustrated in fig. 9, and the preliminary hydraulic tests on the corrugated type of sheath have already shown that it has adequate strength to function satisfactorily in any of the accepted types of oil-filled or gas pressure cable without external metallic reinforcement. Even the initial volumetric expansion associated with the corrugated construction is negligible at the maximum working pressures so far envisaged for such cables.

FIELD INSTALLATIONS.

Argon arc welded aluminium sheathed cable has been used in the important new distribution systems required for the recent extensions on the Company's Wembley Estate, including over 1,000 yards of 11,000 volt ring main cable. The bulk of these cables was buried direct, but there were also some difficult duct runs which were successfully negotiated, the work being greatly facilitated by the remarkable flexibility and lightness of the cables which were

Fig. 10.—Demonstration of the ease of handling of cable being installed.

all of the corrugated type. Jointing presented no difficulty to men with normal experience in the handling of lead-covered cables. No special training was given apart from a demonstration of the "tinning" of the surface of aluminium with a proprietary tin-zinc alloy as a preliminary to plumbing with ordinary wiping solder.

The accompanying photographs (figs. 10 and 11) were taken during the installation work.

It may be stated in conclusion that this new method of manufacture has brought into being a light metal sheathed cable from which the prevailing disadvantages of this type, excessive stiffness and limitation in length, have been eliminated ; that this has been effected in the case of the corrugated type with a greatly reduced consumption of aluminium per unit length of cable ; that important modifications in high voltage cable construction made possible by the resistance of the corrugated cable sheath to crushing and distortion during bending, offer the prospect of mechanically stronger high voltage underground power transmission lines at a cost lower than that of the equivalent lead-covered cable, and of any previously existing equivalent aluminium sheathed cable.

Present effort is being directed towards this last-mentioned development, from which it is expected to derive some outstanding advantages in the special field of high-voltage underground cable.

Fig. 11.—Installation of corrugated aluminium sheathed cable showing flexibility.

Square Wave Transformers and Their Use in Static Control of Mercury Arc Rectifiers

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INTRODUCTION.

THE control grid in a mercury pool cathode rectifier performs the function of preventing the associated anode from carrying current until such time as it is desired that it should do so. Generally it may be said that, when the grid is made considerably negative in voltage with respect to the cathode, the anode will not ignite; and when the grid is made positive, the anode will ignite if at that instant it is itself positive with respect to the cathode. The precise grid potential at which anode conduction will occur depends on the geometry of the rectifier vessel, the resistance of the grid circuit, the temperature of the rectifier vessel and the load on the rectifier. For a given equipment the first two factors will be constant, but the latter two will vary and cause an unpredictable variation of the critical grid potential. For this reason the control of the grids by the application of a sinusoidal potential has been largely abandoned, since a change in critical grid potential leads to a change of the instant of anode ignition sufficiently great to cause an unacceptable change in rectifier output voltage. The effect of this voltage change is most noticeable when two rectifiers are operated in parallel, with the grids of each excited from the same system. The effect of an increase of load is usually to make the critical grid potential less positive (or more negative). With a sinusoidal grid potential this results in an advance of the anode firing instant and consequently an increase in output voltage. Thus with two rectifiers in parallel, if one momentarily takes more current than the other it will tend to increase its output voltage, while the other will tend to reduce its voltage, and the unbalance of load will be increased.

In order to secure reliable operation under all conditions and arrangements of rectifiers it is therefore necessary to provide a grid exciting voltage which changes (from negative to positive) so quickly that normal changes of critical grid voltage cause negligible shift of the instant of anode firing and consequently negligible change of rectifier output voltage. Of course, this can be achieved with a sinusoidal grid voltage by increasing its amplitude sufficiently, but the voltage which is then necessary is usually much higher than that desirable in a grid circuit. Consequently a grid potential of non-sinusoidal shape, with a very steeply rising front combined with a reasonable peak value, is required.

Since the grid exercises no control once the anode has fired, it would at first appear that the duration of the grid wave may be made extremely short. In general this is not the case. If a rectifier, fed from a transformer with interphase transformer, is supplying a load of low inductance but containing an opposing e.m.f., the anode conduction is discontinuous at low loadings: it is necessary to ignite each anode twice per cycle to secure correct operation. If this is not done a discontinuous change in voltage occurs as the load is increased through the value at which the anode burning becomes continuous. In the case where a bridge connection of single anode rectifiers is used, pairs of anodes operate in series and under conditions of load when discontinuous burning occurs it is also essential to ignite each anode twice to secure stable operation.

From the above it will be seen that it is necessary for the grid voltage to remain positive with respect to the critical grid potential for a time slightly in excess of half the normal anode burning time. With the most commonly used systems, i.e. double 3-phase transformer with interphase transformer and 3-phase bridge, this demands a grid voltage duration slightly in excess of sixty electrical degrees.

The most commonly used method of adjusting the instant of anode firing is to feed the grid

transformer from a phase shifting transformer which consists, essentially, of a wound rotor induction motor with locked rotor; the phase being adjusted by moving the rotor through the desired angle. A hand-wheel or pilot motor may be used to move the rotor, or some form of

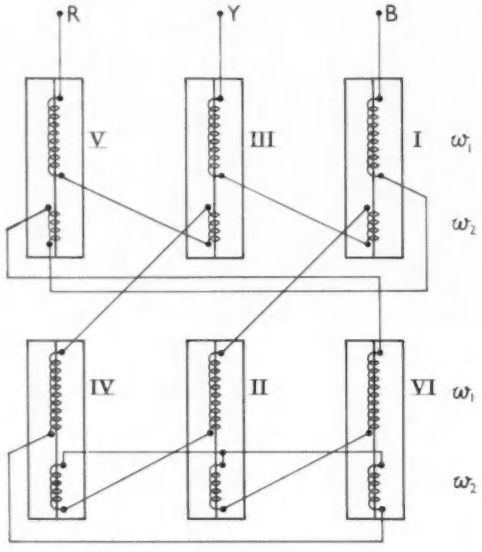


Fig. 1.—Square wave transformer : arrangement of primary connections.

hydraulic regulator. In modern equipments there is an increasing tendency to prefer totally static operation, partly for the sake of reduced maintenance and partly in order to make use of the inherently rapid response provided by grid control. Furthermore, increasing use is being made of closed loop control systems using electronic or magnetic amplification in order to secure high accuracy and rapid response in the control of voltage, current, speed, position, etc. For these purposes a system is necessary in which the phase is varied automatically as a function of a controlling direct current. The desiderata of such a system are :

(*a*) the power needed for exercising control should be small enough to be handled by amplifiers of reasonable size and cost ;

(*b*) the speed of response should be adequate ;

(*c*) the output waveform to be applied to the grids of the rectifier should be approximately constant in amplitude and shape, over the whole range of control ;

(*d*) the angular shift obtainable should be capable, when required, of covering the range of inversion as well as rectification, that is more than 150°.

PEAKY WAVE TRANSFORMERS.

The desired transformation of a sinusoidal wave into one of rectangular shape demands the employment of non-linear elements such as saturated iron cores, thermionic valves or metal rectifiers. Saturated core reactors have been used, with some preference, on account of their inherent reliability, but they seem at first sight not to lend themselves easily to the generation of other than peaky waves. In some earlier designs of grid control circuits the grid voltages have been produced by forcing a sinusoidal current through the magnetising winding of a highly saturated iron core, and making use of the peaked voltage generated in a secondary winding during the short interval when the core is forced through the unsaturated portion of its magnetic characteristic and the flux is suddenly reversed. The simplest arrangement satisfying this condition consists of a relatively large air-gapped reactor connected in series with the primary winding of a closed iron core reactor, the latter designed to saturate and carrying a secondary winding in which the peaky grid voltage is generated. Magnetic circuits in which the series connection of air-gapped reactor and saturated reactor was replaced by a parallel connection of magnetic flux paths on a 3-legged reactor gave the same result.

In this scheme, however, during the major part of each cycle, the sinusoidal voltage which is being transformed into one giving the desirable steep rise is absorbed uselessly in a series reactor. Preferably this voltage could contribute to the desirable rectangular wave shape. This is an important feature of the square wave transformer to be discussed. The earlier system lent itself to a simple phase shift by a superposed D.C. magnetisation, but this led to the necessity for a separate reactor group for each phase of a polyphase rectifier, because only one of the two peaky voltages generated per cycle in each transformer can be used in conjunction with the D.C. control: the positive and negative peaks are shifted in opposite directions by the D.C. signal.

THE ELEMENTARY SQUARE WAVE TRANSFORMER.

The first square wave transformer, which avoids the fundamental disadvantages of the elementary peaky wave transformer, was derived from an earlier development of a saturated reactor group in which the harmonics are com-

pensated by suitable phase displacements of the fluxes in two or more 3-phase groups. It was found that the principle of mutual compensation of harmonics worked equally for series and parallel connections of the windings, provided that the correct phase shift of fluxes was obtained in the various cores. Thus a transformer group consisting of six 1-phase cores, fed from a 3-phase supply can be made to take a current which is free from all harmonics excepting the 11th and 13th, 23rd and 25th, etc. That means only harmonics of the order $2kp \pm 1$ ($k = 1, 2, 3 \ldots$) will appear if p fluxes in p cores are excited in a completely symmetrical sequence during the cycle of the supply frequency. The fluxes must be so displaced in phase that their zero passages follow each other at equal intervals of $\frac{\pi}{p}$, or of 30° for a group of six cores (since the flux in each core has two zero passages per cycle).

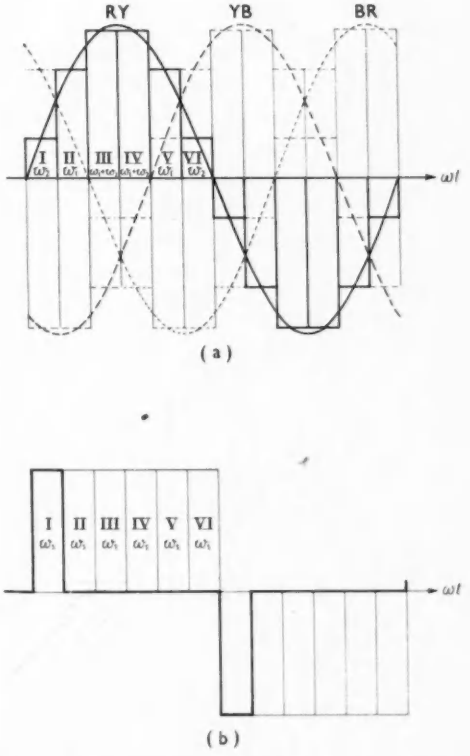


Fig. 2.—Primary (a) and secondary (b) distribution of 30° impulse waves.

Now since this principle is valid whether the fluxes are developed by series, or parallel, connections of the individual windings it is obviously possible to obtain the sinusoidal magnetising current (corresponding to that determined by the air-gapped reactors in the earlier scheme) directly by suitable interconnection of windings on the saturated transformer cores themselves (and these are, in any case, needed for a poly-phase rectifier) so that the principle of mutual compensation of harmonics is satisfied. The required primary connections for six transformer cores is shown in fig. 1. Each transformer primary is excited as part of a 3-phase zigzag circuit having a turns ratio $\frac{w_2}{w_1} = 0{\cdot}366$ so that the fluxes of the two 3-phase transformer groups are displaced by 30° relative to each other. As the zero passages of fluxes in each 3-phase group automatically follow upon each other at 60° intervals, this displacement gives the symmetry of zero passages through the cycle, as postulated.

If the compensation of harmonics in this system were complete, i.e. the resulting magnetising current purely sinusoidal without even the 11th and 13th harmonics, the voltages during the zero passage of each flux would again be very peaky. The effect of the 11th and 13th harmonics is to spread out the zero passage of the flux over a period of 30° so that the sinusoidal voltage, applied between each two of the supply terminals, finds at every instant one winding which is not effectively short-circuited by iron saturation. Consequently in any secondary windings on any one of the cores there will now be generated voltages which have an almost rectangular shape and a duration of 30° each. The three primary voltage waves are thus cut up into nearly rectangular blocks of different amplitude, but equal width of 30°, as shown in fig. 2a, and are transformed into the rectangular block waves, shown in fig. 2b, which can be picked up in any secondary windings w_s (not shown in fig. 1). These secondary windings can be connected in series so that the 30° rectangular waves may be combined to produce wave shapes of a variety of types. A 6-core transformer group can of course give only waves which are combinable from block waves of 30° duration each. The 60° wave, postulated earlier for the supply of the relevant grid voltage, is obtained by adding two contiguous 30° block waves of equal amplitude, by joining in series an equal number of turns of the secondary windings. It is obvious that one 6-core transformer group of this type is sufficient to feed all the grids of a 12-phase rectifier, since twelve similar voltages are obtainable displaced in phase by intervals of 30°. Alternatively, the

duration of each output wave could be chosen to be 30°, 60°, 90°, etc., up to 180° if this were desirable. The combination of two waves, giving a 60° wave, has been found to be the most satisfactory for practical requirements of large rectifiers.

Sometimes, for example, with Graetz connected rectifiers, a reliable reignition of the same anode after 60° may be vital, as already pointed out in the Introduction. In this case, if the combination of 2 adjacent 30° waves fails to give a sufficient margin of safety, one may connect secondaries so as to give two 30° waves at 60° interval, i.e. there will be two 30° impulses separated by a gap of 30°.

THE SIMPLIFIED SQUARE WAVE TRANSFORMER.

The physical correspondence that exists between the changing flux in a magnetic core and the voltage present in its winding, and also that between the magneto-motive force and the current in the winding, permits us to make the equivalent of electrical circuit interconnections by the juxtaposition of magnetic flux paths. Thus, in a circuit network containing several transformer-like objects, e.g. in fig. 1, wherever there are two cores which are subject to an ampere-turn pressure by windings upon them which are in series with each other, it is legitimate to position these cores together and to excite them by a common winding. The voltage present in this common winding will be the same as the sum of the voltages in the two previous windings.

When this principle is applied to the square wave transformer connection, shown in fig. 1, a number of alternative possibilities are evident. One of these is of particular value since it greatly simplifies the design, and the manufacture, of square wave units.* In this adaptation, parts of the two cores carrying the two long windings (w_1) in each primary phase are put together and excited by a common long winding. The square wave unit can then be built using three shell type transformer cores of standard punched laminations, and the diagram for the primary side connections become that shown in fig. 3a. The middle limb of each of the cores is energised by a winding w_1 in one of the three primary phase paths, and the two outer limbs also carry windings w_2, one in each of the other two primary paths : these serve to advance the flux in one part of the core, and retard it in the other, by 15°. The voltages generated in the outer coils consist of rectangular pulses of 30° duration, and that in the middle coil of pulses of 60° ; the latter being effectively the result of the addition of the two former voltages. Fig. 3b gives diagrammatic waveforms illustrating how the sinusoidal voltage between two of the primary supply leads is opposed by the combination of rectangular pulses, and fig. 3c represents the vector diagram of the fundamentals in all pulse waves for the complete primary circuit.

When the unit is to be used for supplying the grids of a 6-phase rectifier, centre-tapped secondary windings will be provided on each middle limb, thus giving six outputs progressively displaced in phase by 60°. In the case of a 12-phase rectifier, six more intermediately phased outputs are required, and these could be obtained by secondary windings on the outer limbs suitably connected in pairs. However, it has been found more satisfactory, for convenience in manufacturing, to use two

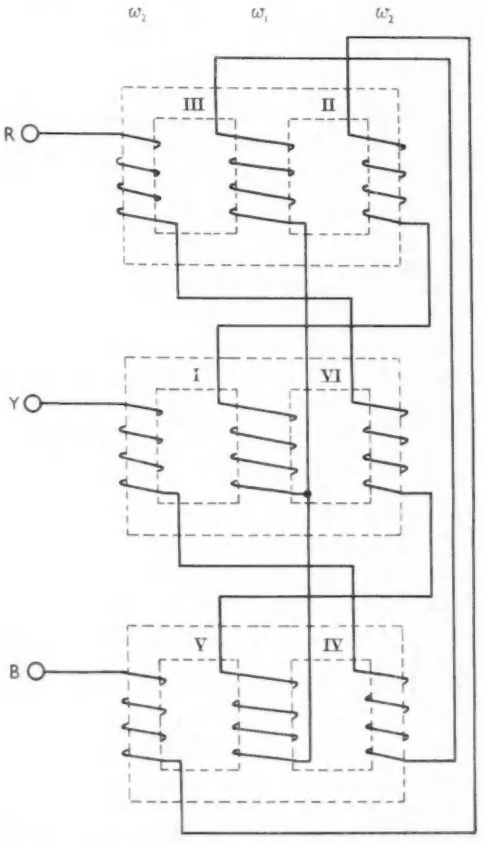


Fig. 3.—(a) Simplified square wave transformer primary circuit.

* Brit. Pat. 619337.

6-output units instead, with their primary supplies displaced in phase by 30° relative to each other. This means that only one type of square wave unit need be stocked.

The advantages in construction which accrue from the simplified arrangement, in comparison with the earlier one using six separate cores, can be gauged from the following table, which refers to the requirements for feeding six grids :

	No. of Core Structures	No. of Primary Windings	No. of Secondary Windings
Six-core arrangement	6	12	12
Three-core arrangement	3	9	6

An added advantage of the simplified scheme is that, because there is only one primary winding on each core leg, there is a useful gain in winding space by the avoidance of inter-winding insulation.

It has been found that silicon-steel laminations of normal transformer grade are quite suitable for units for the grid-control of mercury arc rectifiers. In the case of very small units, for instance for the precise control of thyratrons, there is an advantage to be obtained by using nickel-iron alloys. In the smaller sizes the design is restricted by copper heating, so that the lower magnetising current of nickel-iron is of value. Also a larger output power can be taken from nickel-iron cores before the desirable sharp rises in the output waveform are spoilt. A square wave transformer group built on three shell type cores of Radiometal, with a cross sectional area of $\frac{1}{2}$ sq. in. (middle limb), is easily able to provide an output power of 25 watts total. Fig. 4 illustrates a unit of larger size.

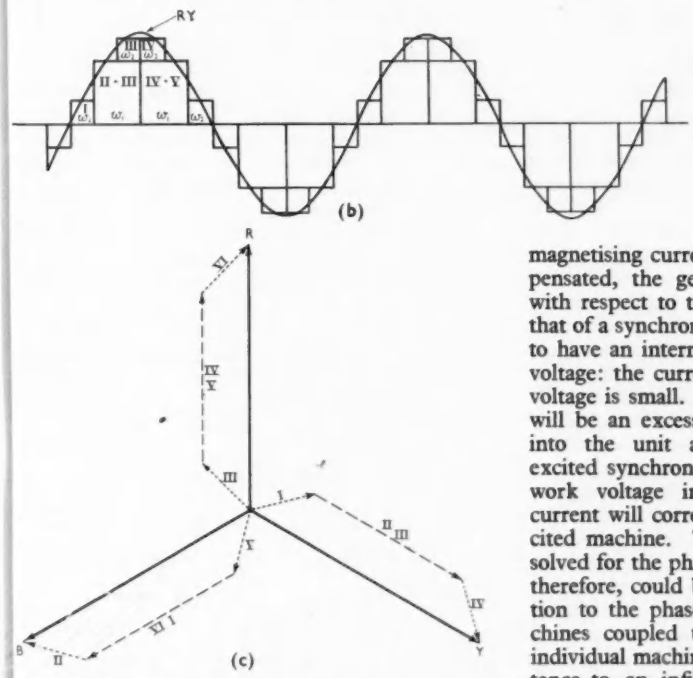


Fig. 3—(b) Distribution of 30° and 60° impulse waves in a primary phase of the simplified square wave transformer.

(c) Vector diagram of fundamental components of voltages in primary windings of simplified square wave transformer.

PRINCIPLE OF THE " PHASE SHIFT NETWORK ".

A set of saturated transformers of the kind shown in figs. 1 and 3a takes, of course, a magnetising current which rises first very slowly and then very sharply when the applied voltage is increased. If capacitors are connected in parallel with these reactors, so that the average magnetising current at the rated voltage is compensated, the general behaviour will—if seen with respect to the supply network—be almost that of a synchronously rotating machine excited to have an internal e.m.f. equal to the network voltage: the current to be supplied at the rated voltage is small. If the voltage decreases, there will be an excess of capacitive current flowing into the unit as in the case of an over-excited synchronous condenser; and if the network voltage increases the lagging reactive current will correspond to that of an under-excited machine. The problem which had to be solved for the phase shift control of this voltage, therefore, could be expected to have some relation to the phase shift occurring between machines coupled through an inductance, or an individual machine connected through an inductance to an infinitely powerful busbar. This led to the following solution.

The loaded square wave transformer with capacitive compensation of its magnetising current corresponds to a loaded synchronous motor. Now, if a motor is supplied from a fixed

voltage through a reactance X (including its own reactance which is responsible for any phase displacement between rotor and terminal voltages), the angle θ, between the rotor voltage E_2 and the fixed supply voltage E_1, is related to the

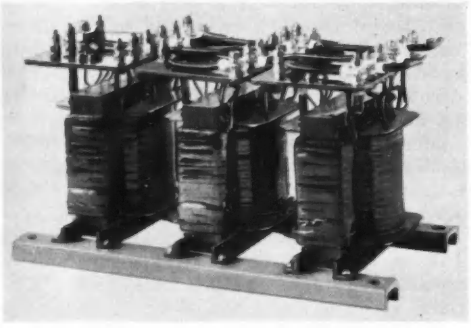


Fig. 4.—Simplified square wave transformer, 900 VA input, suitable for one to six 6-phase rectifiers.

load P of the motor by the well-known condition

$$P = \frac{E_1 E_2}{X} \cdot \sin \theta \qquad (1)$$

The motor may now be replaced by the compensated square wave transformer, the load on which may be represented by a shunt resistance R referred to the phase voltage of the supply system so that, neglecting losses in the transformer,

$$P = \frac{E_2^2}{R} \qquad (2)$$

Therefore

$$\sin \theta = \frac{E_2}{E_1} \cdot \frac{X}{R} \simeq \frac{X}{R}, \text{ since } E_2 \simeq E_1 \qquad (3)$$

We can therefore control θ by varying X within certain limits. $\theta = 0$, for $X = 0$, is the smallest conceivable angle, $\theta = 90°$, for $X = \frac{E_1}{E_2} \cdot R$

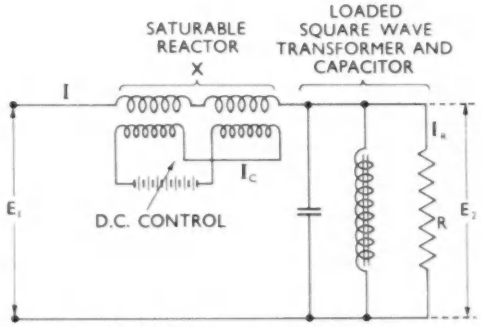
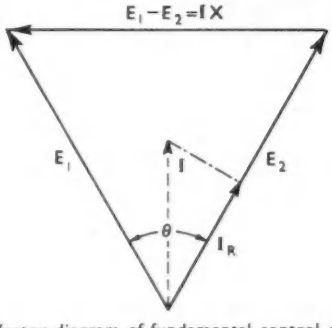


Fig. 5.—(a) Fundamental control circuit.

is the theoretical maximum, if X is a practically linear reactance with negligible losses. This limitation is appreciably removed if the variable reactance takes the form of a reactor which is controllable by D.C. saturation and which itself reaches its A.C. saturation voltage at the maximum permissible voltage difference between E_1 and E_2.* The resulting scheme giving a practical control range of about 80° is shown in fig. 5a. Fig. 5b shows the vector diagram and fig. 5c the well-known control characteristics of a saturable reactor from which the relation between θ and the control current I_c may be derived by straightforward geometry if the saturated reactance of the square wave transformer is small (E_2 = constant) compared with the maximum coupling reactance.

WIDE ANGLE CONTROL.

The angle of about 80° to which the simple scheme readily lends itself is not sufficient in those cases where the variation of the grid ignition angle must cover the transition from rectification to inversion, as was pointed out earlier. This requirement can be satisfied by an expansion along the same lines which have been found to make A.C. power transmission possible (in theory) over arbitrary distances, and with arbitrarily large phase displacements between sending and receiving end voltages. There is theoretically no limit to the displacement angle if the voltage is supported at a sufficient number of intermediate points along the line, and with sufficient "stiffness", in accordance with "Baum's principle". In other words, it is only necessary to subdivide the controllable reactance X into a number of sections and to fit further saturated reactors with capacitors in parallel, but without load resistances, at the intermediate points. The resulting arrangement



(b) Vector diagram of fundamental control circuit.

* A theoretical derivation of the maximum theoretical displacement angle in a case of this kind may be found in the *Swiss Bull. S.E.V.* 1936, p. 571.

in the case of a 3-element chain is shown in fig. 6. The maximum phase shift control achieved with a laboratory model of this network was just over 270°.* In practice, a 2-element chain is found to satisfy all requirements met with so far, and may be used to control phase shift up to 160°.

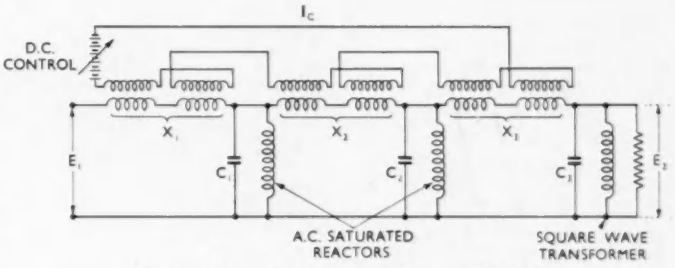


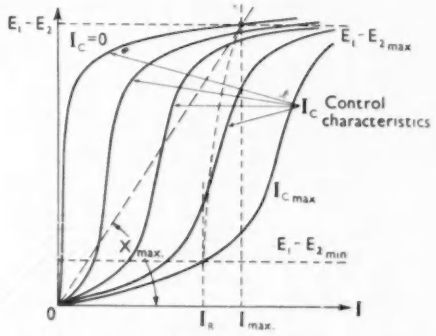
Fig. 6.—Three-element wide angle control chain.

THE PRACTICAL CIRCUIT.

MAIN COMPONENTS OF THE CIRCUIT.

The diagram of a complete practical grid control network is shown in fig. 7. The (D.C.) saturable reactors, A.C. saturated reactor, square wave transformer and condensers C_1 and C_2 will be recognised from the preceding theoretical discussion. The saturable reactors are shown in diagrammatic form. They are constructed with six A.C. coils and six associated A.C. flux paths linked with a common D.C. coil. Pairs of A.C. coils are connected in series with each other and in series with one A.C. line. Details of the square wave transformer connection are omitted in fig. 7. The A.C. saturated reactor has a core and primary winding system which is identical with that of the square wave transformer, but has no secondary windings.

A prephasing transformer is included in order that it shall be possible to arrange that the movement of phase of the grid wave is correctly related to the phase of the main rectifier anode supply. This is adjusted during setting up and is not altered thereafter.



(c) Control characteristics of saturable reactor.

Grid current limiting resistances *RG* are provided, and a resistance *RB* is connected across the negative bias supply. The latter is a transformer and metal rectifier arrangement, with an output voltage of approximately half the peak value of the square wave secondary voltage.

The resistances *RL* provide a small permanent load on the network and are used to make up the total power which must be transmitted to give correct angular control, in accordance with the requirements already set out.

CURRENT DISTRIBUTION IN THE GRID CIRCUIT.

If the square wave transformer is energised when an auxiliary arc exists in the rectifier but when the main anodes are not energised, the grids will function as anodes and a D.C. current will flow from the rectifier cathode to the grid transformer secondary neutral point. This current is limited mainly by the grid resistors. A small D.C. voltage additional to the negative bias voltage appears across *RB*. If this resistance were omitted, most of the D.C. voltage due to grid rectification would appear across the negative bias rectifier, either causing damage to it due to excessive inverse current or, if the negative bias rectifier is made large enough to withstand the total inverse voltage, causing unsatisfactory operation due to the passage of inadequate grid current.

If the main anodes of the rectifier are now connected to a transformer having an interphase transformer and the rectifier is loaded to a value slightly in excess of transition load, the grid current distribution becomes completely changed. When the main anodes are carrying load, grid current can pass in either direction. Now, since a main anode conducts for 120° the grid current for the first 60° will be positive (i.e. current flow in conventional sense from grid

* Note that this experimental result corresponds to a model proof for the possibility of long-distance A.C. power transmission with a line stabilised by saturated shunt reactors over a distance of over 2,000 miles (including machine reactances).

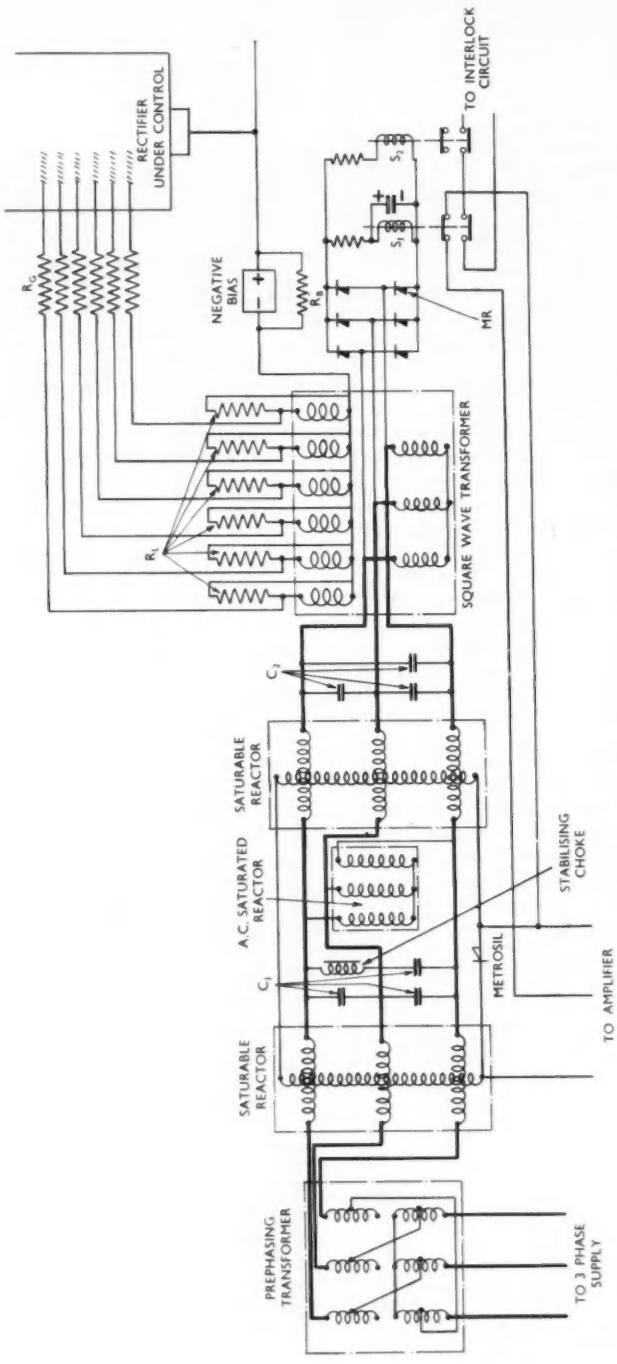


Fig. 7.—Complete grid control circuit.

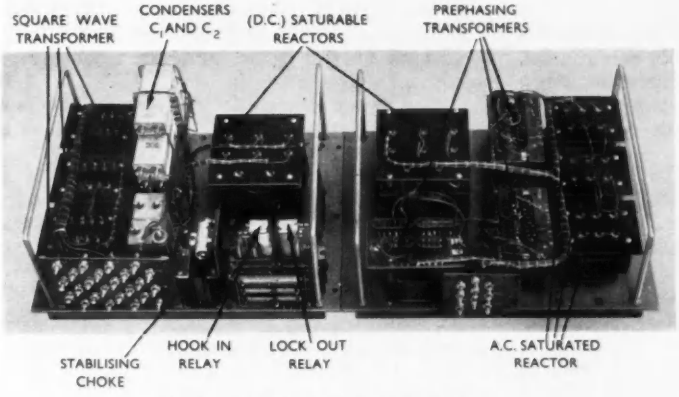


Fig. 8.—Complete grid control network.

to cathode), and for the second 60° it will be negative. With a negative bias voltage equal to half the square wave peak voltage the values of the positive and negative grid currents will be substantially the same; it follows therefore that no average current will flow in the grid transformer neutral. In fact, no current at all will flow in the neutral, the positive current in any grid will be supplied from the grid immediately preceding it in the sequence. Thus the negative bias supply is not loaded otherwise than by the resistance *RB*.

If, now, the load on the main rectifier is increased, the anode burning period will increase due to the anode overlap. The duration of the negative grid current now exceeds that of the positive and a small average direct current flows in the grid transformer neutral. This causes a slight increase in the load on the negative bias rectifier, which, however, with normal angles of overlap is not significant.

Stability of the Fundamental Voltage Distribution.

If the network is connected to an A.C. supply of correct voltage when the saturable reactors are not excited with direct current, it will be found that the correct square waveform is not developed. Only a small, more or less sinusoidal, voltage appears. If now the saturable reactors are fully saturated the correct square waveform is developed. The D.C. saturating current may then be switched off without collapse of the square wave. This operation has been termed "hooking in" the network. "Hooking in" is performed automatically by the metal rectifier *MR* and the relay S_1. An auxiliary D.C. supply is switched to the D.C. coils of the saturable reactors by the normally closed contacts of relay S_1. This relay opens after a slight time delay (ensuring that the conditions required for establishing the square wave are maintained for long enough to give reliable hooking in) when the full primary voltage on the square wave transformer is established. If the supply voltage falls excessively, the network will "unhook" and the square wave will collapse. Production networks will withstand a voltage dip of rather more than 15 per cent without unhooking with no D.C. in the saturable reactors. In the event of a very severe supply dip, and consequent collapse of the square wave, the quick acting relay S_2 opens and operates interlock circuits to disconnect the load from the rectifier; this is necessary since the hooking in relay S_1 will operate to re-establish the square wave, and this must not be allowed to occur with a load connected to the rectifier. It should be understood that the protection afforded by the relay S_2 is a safeguard against a very rare occurrence, and outages for the above reason occur with negligible frequency.

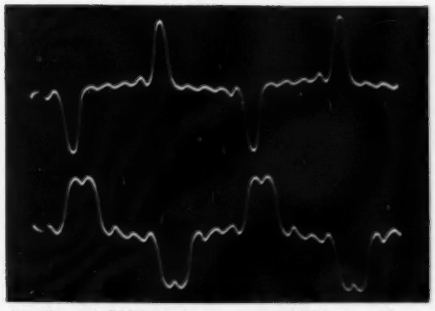
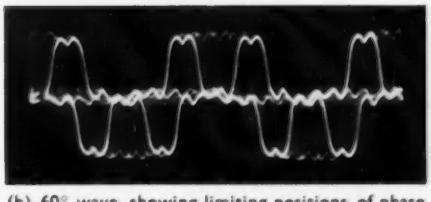


Fig. 9.—(a) 30° impulse waves and 60° waves built up from two 30° waves.



(b) 60° wave, showing limiting positions of phase shift, and four intermediate positions.

HARMONIC STABILITY.

It is found with this type of network that a form of harmonic instability may be encountered. This may best be described by saying that when instability occurs the square wave form, if examined on the screen of an oscilloscope, appears to " wriggle ".

The stabilising choke which is connected in series with one of the condensers C_1 in fig. 7 effectively corrects this tendency. It is dimensioned to resonate with the condenser at twice the supply frequency.

RANGE, SENSE AND DYNAMIC FEATURES OF CONTROL.

With the two stage network as shown in figs. 7 and 8 it is possible to achieve a phase shift of at least 180°. However, for normal grid control work not including inversion a shift of approximately 120° is adequate, and the components are normally dimensioned so as to give this order of shift. In this way the tolerance of the network to supply voltage variations is increased. Fig. 9 demonstrates oscillograms of the waves (A) and phase shift (B) achieved.

The sense of control by the network is that an increase of D.C. saturating current causes an advance of grid phase, and so an increase of rectifier output voltage.

The power required for full advance of phase is slightly under 5 watts, so that control by a small electronic power valve or a small magnetic amplifier is a simple matter.

Usually, when the network is used, it forms part of a closed-loop system of control for the rectifier. The equivalent transfer function of the network is of the form

$$\frac{1}{p^2 + Ap + B}$$

and satisfactory stability, with excellent response, has been achieved using suitable stabilising means.

Electronic control of rectifiers using this phase shift network has already been applied successfully to tube drawbench control, planer control, printing press control and current regulation for electrolytic processes.

Equipments for high accuracy speed control are in process of manufacture, and many further applications are envisaged.

Street Lighting Installation at Slough

The illustration shows part of the lighting on the main road at Slough, Buckinghamshire. Open type, cut-off reflector lanterns are used with 250 watt Osram mercury lamps. The lanterns are mounted on concrete columns at intervals of approximately 100 ft. and give remarkably even, shadowless illumination.

These lanterns are particularly valuable for use in proximity to airfields, as the cut-off feature precludes any possibility of their being confused with the lighting on the airfield.

TECHNICAL LITERATURE

A DIGEST OF RECENT BOOKS, ARTICLES AND PAPERS, BY MEMBERS OF THE G.E.C. AND ITS ASSOCIATED COMPANIES

CONTROL SCHEME FOR IMPROVED ALTERNATOR STABILITY ON LOW EXCITATION.

By E. Friedlander (Consulting Engineer, Witton Engineering Works).

A paper read at the Conférence Internationale des Grands Réseaux Electriques à Haute Tension, 1952.

An argument is advanced for the automatic supervision of the approach to instability of an alternator due to low excitation which should be based preferably on the angle between the rotor and the terminal voltage. Two phase-sensitive systems are described: one using a mechanical rectifier in conjunction with a polarised relay, the other dependent upon an auxiliary permanent-magnet generator in conjunction with a phase discriminating relay of low inertia. The proposed method of influencing the operation of a machine approaching the critical limit is to insert a motor-controlled resistor into the circuit of the automatic voltage regulator. Different speeds of control for raising and lowering the resistance, as well as transient resistance switching in the regulator circuit, are designed to increase the speed of reaction and to prevent over-shooting of the control. Laboratory experiments have given very satisfactory results. They prove that the scheme solves the problem of preventing instability with a minimum of interference with normal operation and a minimum increase of terminal voltage when unfavourable network conditions threaten to throw the protected machine out of step.

THE MODERNISATION OF A 132 kV CIRCUIT BREAKER.

By C. J. O. Garrard (Witton Engineering Works).

The Engineer, Vol. CXCIV, July 25th, 1952.

In the early days of the Grid a nominal breaking capacity of 1,500 MVA was considered adequate for 132 kV switchgear, but, as the system grew, the fault level at points near large generating centres rose until many switching stations needed circuit breakers of 2,500 MVA or even 3,500 MVA capacity. To avoid the expense of widespread replacement means were found of modifying the 1,500 MVA circuit breakers, thereby increasing their breaking capacity. This article describes the modernisation of one form of 132 kV circuit breaker which was originally supplied for the Central England and South-West England areas of the Central Electricity Board.

CIRCUIT-BREAKER TESTING STATION: RESTRIKING-VOLTAGE AMPLITUDE FACTORS.

By J. S. Cliff (Witton Engineering Works).

A paper read at the Conférence Internationale des Grands Réseaux Electriques à Haute Tension, 1952.

The report deals with the factors which affect the amplitude of the inherent restriking-voltage oscillation, and gives data regarding the amplitude factors which are obtained on the standard test-circuits of the circuit-breaking testing stations of the Association of Short-Circuit Testing Authorities (A.S.T.A.).

STREET LIGHTING

By J. M. Waldram (G.E.C. Research Laboratories).

Edward Arnold & Co., London, 1952.

The book is addressed to the municipal or lighting engineer who has to handle public lighting as one technical matter among many others. Mr. L. T. Minchin has contributed the chapters dealing exclusively with gas apparatus.

The author admits that specialists have produced endless researches, theories, surveys and methods of calculation, to the bewilderment of the plain engineer who finally proceeds by rule of thumb. In this book one consistent method of treatment is adopted which is believed to be sound and realistic. In Part I the mechanism of street lighting is outlined with relevant results of theoretical work. Part II treats of the layout of installations of various types; Part III discusses the equipment, and Part IV covers miscellaneous matters. Photometric terms and methods of calculation are given in Appendices. The characteristics of light sources and a pictorial summary of design recommended for traffic routes are also placed in Appendices for ready reference.

RECEIVERS FOR USE AT 460 MC/S (454).*

By E. G. Hamer (G.E.C. Research Laboratories).

Wireless Engineer, Vol. 28, pp. 323-329, November, 1951.

The theoretical noise figures of various types of receiver input circuits are derived and compared with the measured values at frequencies of 460 Mc/s. and 40 Mc/s. Noise figures for typical receivers using direct silicon crystal mixers, and simple RF valve amplifiers are given and it is concluded that a noise figure of 6 to 10 db may be obtained with reasonably simple designs.

THE MODULATION CHARACTERISTIC OF CATHODE-RAY TUBES IN TELEVISION (472).*

By R. B. Mackenzie (G.E.C. Research Laboratories).

Brit. Jour. Appl. Phys., Vol. 3, pp. 54-8, February, 1952.

The ambiguity which arises in defining the modulation characteristic of a television cathode-ray tube in terms of gamma is discussed. A method of eliminating this ambiguity is proposed, which is partly empirical, but leads to a simple mathematical treatment. Theoretical and actual characteristics for two different types of tube are compared; the effect of stray light and the variation with luminance of the sensitivity of the human eye are discussed.

APPARATUS FOR THE MEASUREMENT OF SMALL DIFFERENTIAL EXPANSIONS AND ITS USE FOR THE STUDY OF FUSED SILICA (476).*

By R. W. Douglas and J. O. Isard (G.E.C. Research Laboratories).

Jour. Sci. Insts., Vol. 19, pp. 13-15, January, 1952.

The differential expansion is magnified by an optical lever, the sensitivity of which is increased by an arrangement of two graticules, the image of one acting as a vernier to the other. Changes of length of 10^{-5} cm. can be determined. The apparatus has been used to measure differences in the thermal expansion of samples of fused silica which had been given different heat-treatments.

THE EMISSION FROM OXIDE-COATED CATHODES IN AN ACCELERATING FIELD (479).*

By D. A. Wright and J. Woods (Research Staff of the M.O. Valve Co., Ltd., at the G.E.C. Research Laboratories).

Proc. Phys. Soc. B, Vol. LXV, p. 134, 1952.

It is shown that the steep rise of current with accelerating field in a diode with an oxide-coated cathode cannot be fully explained either by surface roughness or by patch effect. This leads to a theoretical treatment, based on the existence of a space-charge zone immediately inside the coating. The effects of partial space charge on the relationship between field and anode voltage are discussed, and the diode characteristics of oxide cathodes can then be calculated for accelerating fields as a function of the coating parameters. The results are shown to be in agreement with experiment, and to confirm values of coating conductivity, electron density and mobility as determined directly by conductivity and Hall effect measurements.

AN APPARATUS FOR THE DIRECT MEASUREMENT OF THE SATURATION TEMPERATURES OF SOLUTIONS (489)*

By L. A. Dauncey and J. E. Still (G.E.C. Research Laboratories).

Jour. Appl. Chem., July, 1952.

Apparatus is described whereby the saturation temperature (with respect to a given solute) of a solution of known or unknown composition can be measured while the bulk of the solution is at a temperature several degrees above or below that of saturation. There is no need to bring the whole of the solution into equilibrium with excess of solute at any time or to change its temperature. In the apparatus a current of the solution is passed through an adjustable heater to a cell containing a piece of solute, and the measurement is based on observation of the refractive-index gradient in the solution near the solid.

The method is of particular value for measuring the degree of saturation maintained in a crystal-growing tank and also for the construction of solubility curves.

HARMONIC DISTORTION OF MODULATION (481).*

By E. G. Hamer (Research Laboratories).

Wireless Engineer, Vol. 29, pp. 212-216, August, 1952.

An analysis is made to determine the harmonic distortion caused by echo signals in a radio system; this analysis being restricted to the cases where the amplitude of the echo is small compared with the wanted signal. A series of monograms is derived for amplitude modulated and frequency modulated signals, where the echo is due to a mismatched aerial feeder cable.

A SIMPLE HOT STAGE FOR THE STUDY OF POLARISING MICROSCOPE INTERFERENCE FIGURES AT ELEVATED TEMPERATURES (486).

By E. G. Steward (G.E.C. Research Laboratories).

Jour. Sci. Insts., Vol. 29, No. 7, July, 1952.

The construction of a very simple microscope hot stage for the study of optical interference figures at elevated temperatures is described. A crystal under examination remains fully accessible, and with a negligible loss of heat in operation cooling arrangements are unnecessary. Temperature may be measured by means of a thermocouple. An example of performance is given.

A SIMPLE FURNACE TEMPERATURE CONTROLLER (490).*

By M. Sheperdson (G.E.C. Research Laboratories).

Jour. Sci. Insts., August, 1952.

A two-position controller is described for use with a thermocouple or D.C. resistance bridge as sensing element. The error signal operates a mirror galvanometer which controls the position of a spot of light on a photocell. This, through a single valve amplifier, controls a thermal relay which switches the power. The circuit is very simple and is arranged to prevent overheating of the furnace whatever probable fault develops.

*** A limited number of reprints is available of those papers marked with an asterisk. Copies may be obtained on application to the Editor, G.E.C. Journal, Magnet House, Kingsway, W.C.2.**